ELECTRO-TELEGRAPHY.

BY

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LONDON:
E. & F. N. SPON, 48, CHARING CROSS.
NEW YORK: 446, BROOME STREET.

1876.

LONDON:
PRINTED BY JAS. TRUSCOTT AND SON,
Suffolk Lane, City.

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INTRODUCTORY REMARKS.

Telegraphy literally signifies the art of writing at a distance, but more generally considered refers to the sending of signals from one spot to another at a distance.

Various modes of telegraphing have been employed in the world's history, but previous to the application of electricity in this direction they all depended on either sound or light as agents.

The most primitive mode of transmitting information was by lighting fires at intervals on commanding positions across country.

The use of cannon, in more modern times, is probably a degree above the last method in its capability for communicating intelligence, as its value would be the same in the daytime as at night, and variety of information could be more easily transmitted.

The employment of the semaphore, a system of telegraphic posts with cross-arms, whose movements, visible from one hill to another, were made to express certain pre-arranged meanings, may be considered the best form of telegraphy previous to the application of electricity. The great defect in all such processes is the limited distance through which they can operate, causing great loss of time in repetition.

All such objections are overcome by the application of electricity to telegraph operations.

There is more than one claimant for the honour of having introduced Electro-Telegraphy into this country. A careful investigation shows that various experiments were made by different persons in several places, here and abroad, which proved that those who made them had a certain acquaintance with the principles of transmitting signals by electricity. But it was an Englishman who first introduced Electro-Telegraphy as a practicable science into England.

William Fothergill Cook, an officer on leave from India, when residing at Heidelberg, witnessed an experiment by Professor Muncke, which led him to conceive the idea of establishing a line of telegraph, to be worked by means of a current of electricity acting on one or more magnetic needles. Soon after, he abandoned his former pursuits, and, in conjunction with the late Sir C. Wheatstone, he set up a line, his first patent being taken out in 1837.

But the first application of *Galvanic* Electricity to telegraphic purposes was proposed, as far back as 1809, by Dr. Soemmerring, Member of the Academy of Sciences at Munich. The Austrian troops had entered Bavaria, and an improved form of telegraph for military objects was called for by the authorities.

The first proposal for a submarine cable is claimed for Baron Schilling, who, it is said, ordered one to be laid uniting Cronstadt with St. Petersburg, through the Gulf of Finland, in 1837.

The object of the following pages is to give a sufficient explanation of the principles of Electro-Telegraphy, with reference more especially to its practical uses. A very much larger work would be necessary to afford a detailed account of all the inventions that are included in its history, and to exhaust the subject in all its connections.

CHAPTER I.

DIFFICULTY OF EXPLAINING THE NATURE OF ELECTRICITY —ELECTRICAL ACTION A DISTURBANCE OF EQUILIBRIUM —ALWAYS MANIFESTED UNDER A TWO-FOLD ASPECT— POSITIVE AND NEGATIVE ELECTRICITY—CONDUCTORS AND NON-CONDUCTORS—ELECTRICAL CIRCUIT, CURRENT, RESISTANCE—INSULATION OF CONDUCTING MEDIUM.

1. To answer directly the question, "What is Electricity?" is, strictly speaking, impossible. Various opposing theories have been held by many whose opinions are worthy of the greatest attention, and, as their conflicting claims to be received as true are nearly equal, the most that can be said is that future discoveries may, perhaps, confirm one or other of them.

2. To illustrate the difficulty of declaring what electricity actually is, we may take the well-known "prime mover" or "agent" steam, and it will be seen that a simple definition which is possible in the case of the latter is impossible for the former. Steam is undeniably proved to be the vapour of boiling water, and this again is a compound of two gases which belong to the list of what are called natural elements, which have hitherto resisted further decomposition. But electricity cannot be analysed in any such manner; it differs altogether from steam in everything that can be said as to its constitution or existence.

3. Electricity is generally classed with Light and Heat as a form of energy. In many respects it resembles Heat more closely than anything else, and it is certainly most intimately associated with that form of energy. It cannot be heard or seen, but it can be felt. It is disputed whether the "something" that is called electricity is always in existence, but only rendered observable under certain conditions, or whether these conditions

are the cause of it—creating it, as it were. Whether electricity is simply electrical force, or whether it is a substance that acts like a Force, is also disputed. It is apparently associated with every substance in Nature, but its existence is only made evident by certain effects which are called effects of electricity.

4. Before this agency was known to mankind it no doubt existed, though the fact only rests on the belief that Nature's laws do not change. It was first observed in amber, the Greek for which is ελεκτρον (electron), and hence its name. What did the first discoverer find? He found that if he rubbed a piece of amber on some woollen fabric it acquired a power previously unseen, namely, that of attracting light objects close to it, but that very shortly they appeared to fall off. There was nothing new that could be perceived (beyond the effect), and it would naturally be set down that here was a property belonging to amber, and found there by rubbing it, and resembling Heat in the fact that friction produces both.

5. It is well, then, to consider that electricity has an actual existence, the fact of which is made known by such effects. Since it is only when made apparent or evoked that it gives evidence of force, it follows that its normal or natural state is one of rest or *equilibrium*, and electrical action must therefore be a disturbance of *electrical equilibrium*. Any means of such disturbance may fairly be said to be a *source* of electricity. In these pages electricity will be considered to mean electrical action, for the sake of more convenient treatment of the subject.

6. Electrical action is invariably manifested under a two-fold aspect. Supposing electricity to be normally united to matter in certain definite, limited quantities, and only to be made apparent when these proportions are disturbed, then it is easily understood that such disturbance involves an increase of the normal or natural quantity of electricity in some particles, and an exactly equal decrease in others; what one loses another gains. This is one view of what happens when electricity is

evoked, or its normal equilibrium destroyed. The other view is, that when this disturbance is made electricity exhibits itself as two-fold—that is, it manifests two exactly opposite qualities. In either of these views it is said that by the disturbance of its original equilibrium we have caused the appearance of, or evoked, *positive* and *negative* electricity. The former theory holds the word *positive* to mean an excess of natural electricity, and *negative* to mean a deficiency. The latter theory holds the *positive* and *negative* to be two *qualities* of electricity, each of which acts in a direction opposite to the other. In either case, any body or object on or from which electricity is evoked is said to be electrified *positively* or *negatively*, as may happen according to its constitution or the means employed to produce electrical action.

7. From this it is possible to understand the statement that "like electricities repel each other, and unlike electricities attract each other," for *positive* electricity in the presence of *negative* tends to *equilibrium* by attraction, and the reverse is the case with either in presence of electricity of its own name. The principle at work is the *tendency to equilibrium*. If there is already too much, more will but increase the irregularity; and with a deficiency, further deficiency but adds to the disturbance. The mathematical symbols, plus (+) for addition, and minus (−) for subtraction, are used to express the words positive and negative.

8. It is usual to regard the earth as a vast reservoir of electricity, from which a quantity can be drawn to fill up a deficiency, and which is always ready to receive a surplus from other bodies. Every body in Nature has its own natural quantity of electricity, and when an object is negatively electrified, or has a deficiency in its normal quantity, there is a tendency to receive a supply from any convenient source. Such an object would receive electricity from the earth if means were furnished according to the laws which govern electrical action; and a body *positively* electrified would tend to part with

its excess in the same way. Where such facilities for establishing electrical equilibrium are afforded, the result is, in fact, the passage of a *current* of electricity.

9. Electrical action is not confined within narrow limits. It can be made to produce sensible effects at very great distances from the seat of the *source*. It is this peculiarity that renders it useful in Electro-Telegraphy. It must, however, have a medium of communication by which its action is transferred. Substances in Nature differ very much in their power to act as such media; in other words, some bodies *conduct* electricity, and with great readiness, while others are said not to do so at all. The former are called *conductors*, and the latter *non-conductors*. Strictly speaking, all substances *conduct* electricity in some degree, and a *non-conductor* is merely a *bad* conductor.

10. They had no paper in the days of the first discoverer of electricity, or he might have attracted little pieces with his piece of amber, as we may now do with a stick of sealing-wax; but after he found that by rubbing his amber he had a means of attracting light bodies, he would very likely inquire why he could not do the same thing if he used a piece of metal instead, and would conclude that the mysterious power resided in the amber only. In fact, he did think so, and hence the name he gave to it. The reason was that the metal was a good *conductor* of electricity, and as fast as it was evoked by rubbing it was *conducted* away through the metal and through his body to the earth. But the amber being a *non-conductor*, the electricity in great measure remained upon it.

11. A body in which electricity is thus disturbed is said to be *charged*, and so remains until the electricity is conducted away. In any case, it must disappear in time, because the atmosphere contains matter which acts as a conducting path, and is always in communication with the earth.

12. The metals generally are the best known conductors of electricity. Such bodies form a ready path

for what it is convenient to call a *current* of electricity. Whatever be its nature, it is usual to consider it as a very subtle fluid, its action being more intelligible when so regarded. Thus a current of electricity can be made to flow along a conducting path between two places at a great distance apart.

13. But the conditions attending this operation are different from those of any other known method of transmission. It is important to remember that in every case of electrical manifestation a complete *circuit* must be formed. In fact, to use familiar language, the current cannot be started unless the path which it is to traverse leads home again. It cannot start from A and travel to B, and cease there; the circuit must be completed before it can be said that B has been reached.

This will not be difficult to account for if we consider what a current of electricity really means. As stated above, a body can be *charged* with electricity, in which condition there is no appearance of a current, but there is the tendency to equilibrium by which the electricity is ever aiming at re-combination with electricity of the opposite kind, or at escaping to earth. If a piece of glass be rubbed with a cloth it will become *charged;* but whatever excess the one has obtained is but the loss of the other, and if they be then touched together the separated electricities re-combine, the action being that of a current. There cannot be a current of electricity without a means of re-combination, which re-combination must be at the place of original disturbance. This "place of disturbance" we call in general terms the *source*, and it must in this view be regarded as having two sides. At some spot the natural electrical proportion is disturbed; electricity is separated into too much (positive) on one side, and too little (negative) on the other side. The very term "separation" involves of necessity the idea of two sides. If, then, no means of re-combination is afforded, the electricities remain separated; but if a *conductor* (par. 9) be made to join the two sides, electricity is set in motion, and a current is the result.

It is with electricity in motion that Electro-Telegraphy has to do, so far as the production of signals is concerned, and, according to present experience, it is in this form only that it can be made serviceable. For this reason we say that a complete circuit is essential, as without it a current of electricity cannot exist. It was stated, however, that a complete circuit must exist in every case of electrical action—and this is strictly true.

14. The necessary conducting path for the current in Electro-Telegraphy is afforded by the wires; thus a telegraph line is in reality a portion of an electrical circuit, but each wire is a separate conductor, and its circuit distinct from that of every other wire. No two wires form one circuit, though they might be made to do so. But in a telegraph line, as from A to B (par. 13), the circuit is not complete without a "return path." The most obvious means of effecting this purpose would seem to be to provide a "return path" of wire, making it, in fact, a duplication of the conducting wire, but it was discovered that this is not necessary; so far from it that, under favourable circumstances, the earth answers the desired end much better. If the line at each end be brought into close communication with the earth by joining it to a buried metal plate, the circuit is complete, for the earth acts the part of the no longer required return wire. If either plate be separated from the wire, or else be kept from communication with the earth, the circuit is broken. When speaking here of a line conducting a current of electricity, it is understood that it is joined to a *source* from which electricity is produced; and further, that if the current is to be made useful, suitable instruments for indicating the passage of a current must be interposed at the right places. If a current pass from A to B, one side of the source at A joined to an earth-plate, the other earth-plate being joined to the other end of the line at B. If, instead

of using the earth, a "return wire" were employed, it would lead from the end at B to one side of the *source* at A, the other side, of course, being connected with the line at that place.

15. The quality of conducting electricity freely makes metallic bodies so useful in cases where an electric current is employed; but the fact that electricity in action is always seeking to be recombined, or to pass to earth, renders it necessary to prevent the current from escaping until its duties are fulfilled. In some respects it resembles a lazy man; it chooses always the easiest path to travel on, and there is no fear of its leaving such a path as a conducting wire and going to earth unless an easy way be afforded. But when a wire leads from one point to another, it must be supported every few yards; and as the only substances that suitable supports can be made of are conductors of electricity—such as iron, or wood, which is sufficiently conductive to defeat the object—there are great numbers of opportunities for the current to escape. In a long telegraph line the posts are, of course, very numerous, and it is necessary to have the points at which the wire is joined to, or touches them well *insulated*. The little bell, or cup-shaped pieces of porcelain or pottery ware fixed in such numbers on the telegraph posts, are *Insulators*. They are intended to "insulate," or separate, the current from the seductive bye-path.* Being made of non-conducting material they prevent "leakage," and though, with the best choice of materials, it is impossible to get one which is totally non-conducting, and so some little escape of the current must occur, yet, comparatively speaking, a line is well *insulated* by the means employed. If a line were laid on the ground, or in water, instead of being supported on posts, the current could not pass; it would be then constantly going to

* Though electricity chooses the best of two conducting paths, yet some part of the current must traverse both. This it does in proportion to the goodness of either path. Thus *some* would escape at every post, though it were not much for each, but the total would amount to a good deal.

earth. The best insulating substances are india-rubber, gutta-percha, sulphur, resin, &c., but as these materials would be unsuitable for employment as insulators in a telegraph line, porcelain or earthenware is used, and when kept dry and clean, insulators of such material answer the purpose.

Lines are often laid underground on land, but in this case they are carefully insulated with a coating of gutta-percha or india-rubber.

16. From these observations it follows that, while a good conductor facilitates the passage of an electric current, a bad one may be said to oppose it. Yet its speed is so excessively great, that although it has been calculated the results give no means of familiarly realising it. All conductors oppose a sensible *resistance* to the passage of an electric current, and the strength of a current, that is, the quantity per second passing from one point to another, depends on the *resistance* of the wire or conductor joining them. A bad conductor does not let the electricity pass so freely as a good one, in other words, presents more *resistance*. The *resistance* of a given conductor, such as a wire, increases directly in proportion to the length; but the thicker it is, that is uniformly, the *less* will be its resistance. The resistance is *inversely* proportional to the cross-section; this means that the larger the cross-section the less the resistance. If we compare two wires of exactly similar material which have been cut through, the resistance of that which shows the smallest surface, or cross-section, is the greater. The larger the wire is, the better it is as a conductor of electricity. In this view two conductors may be considered as two roads, one broad and easy, the other narrow and difficult.

17. Electrical resistance must not be regarded in the same way as a mechanical resistance, such as that experienced by water in passing through a pipe. This arises from friction against the inner surface, and varies when different quantities of water are being forced through; but the electrical resistance of a conductor is

constant, no matter what quantity of electricity be made to pass through it.

18. Other features of electrical action, which are more prominently connected with submarine and underground telegraphy, are considered in the beginning of that section. The substance of the above explanations as regards the fitness of electricity for telegraphic purposes, is that it exists as an agency which can be made to take the form of an incredibly swift current—that it passes freely along certain conducting materials, but its tendency to escape to earth must be prevented by *insulating* the *conductor* with substances that oppose the passage of electricity as much as possible; and, finally, that the earth will always act as one-half of the complete (conductive) circuit which must be established to enable a current to exist.

CHAPTER II.

VARIOUS SOURCES OF ELECTRICITY—QUALITIES DIFFER—GALVANISM—VOLTAIC PILE—ELECTRICITY FROM FRICTION AND FROM CHEMICAL REACTION—COMPARISON OF ELECTRICAL MACHINE AND GALVANIC BATTERY—VOLTAMETER, AND SIEMENS' DIFFERENTIAL DITTO—ELECTRICITY UNCONSCIOUSLY DEVELOPED.

18.* Since electricity (with the exception of Lightning, or Atmospheric Electricity) does not make its existence known unless special means are employed to produce it, we must be prepared to satisfy the inquiries—"How are we to produce it?"—and, "How are we to know when it has been produced?"

There are various *sources* of electricity, or rather means of making electrical action apparent to the senses. It can be done by Friction, or rubbing one matter against another, also by the contact of two dissimilar metals, and by the contact of a metal with a liquid.

Electricity can also be produced by *heating* pieces of metals at their point of junction; Chemical Action is another *source*, and Magnetism and Electricity mutually give birth to each other. Generally, any disturbance of the interior condition of bodies tends to produce electricity—breaking and cleaving certain substances asunder is known to do so. When crystallised sugar is broken in the dark, the light that is seen flashing on it is attributed to electricity. Animal electricity is found in certain creatures, which are able to control its evolution.

19. The electrical action resulting from these various means is presented under different conditions; that is to say, though in each case we produce electricity, yet the qualities differ. It is not necessary to go in detail through all the known methods. It is enough to consider at all closely that which most concerns Electro-Telegraphy, and this source of electricity is chemical action, the representative of which is the Galvanic or Voltaic Battery. It will be well also to notice a few points in connection with the Electrical Machine, the best known source of Frictional Electricity.

20. It may be taken generally that electrical action, however manifested, has always certain definite qualities, though the effects produced by it when obtained from different sources differ so widely that it might be supposed the very nature is different in each case. Using the simplest language, electricity such as that furnished by the electric machine has great force—it is technically said to be of high *potential*, and may be illustrated by reference to lightning, which is merely atmospheric electricity of extreme *potential*, but it is worthless for the purpose of getting a current. Electricity as developed by chemical action presents the necessary conditions for a current, but its *potential* (see chap. III.) is low. When its distinguishing property is high potential, it has enormous power of overcoming resistance, but very little, in quantity, will pass over a given conductor in a given time. The reverse is the case with electricity of a low *potential*, but of quantity sufficient to afford a current freely.

A knowledge of electricity acquired by using the frictional machine only, might without further experience often mislead us as to its nature and character. It is not so very long ago that galvanism was believed to be quite distinct from electricity, and a battery was supposed to produce a kind of action totally differing from that produced by an electrical machine. It is now well understood that both are *sources* of electricity, but produce different qualities. It will be best to examine each separately, and extract as much as possible that is likely to assist the study of Electro-Telegraphy.

21. Let us commence with the Galvanic Battery, which, by the way, may just as well be called Voltaic as Galvanic. Its origin is interesting. At the end of the eighteenth century Professor Galvani, of Bologna, while experimenting on dead frogs with an electrical machine, found by accident that if a metal wire was joined at one end to the *lumbar* (or loin) nerves, and at the other to the muscles of the leg, the limbs contracted sharply, and much more actively if two metals were used joined together. This fact he attributed to electricity existent in the animal, though he had previously produced similar effects with the electrical machine. But Professor Volta, of Pavia, made many experiments to prove that the electricity arose from the contact of the metals, and to him is due what is called the Voltaic Pile, the first attempt at arranging a combination of electrical sources in the form of a so-called battery. The voltaic pile consisted of alternate discs of zinc and copper, soldered together, each successive pair being separated by pieces of cloth moistened with salt and water. Later researches have proved that the electricity thus exhibited as a current is due, in part at least, to chemical action, evidenced in the decomposition of the salt and water, and the union of its constituents with one at least of the metals. (See chap. III.)

22. The original experiment of Galvani was the germ of the improved forms of battery now employed, full explanation of which is given in chap. IV.

It is possible that some readers may not exactly see the connection between Galvani's frog experiment and the action of such an arrangement as Volta's Pile. Volta probably reasoned thus: Here is a case where two metals are in contact under circumstances which will bear improvement, and probably thus afford more important results. I will arrange two metals in such a way that as much surface as possible shall be operated on, and will repeat the arrangement a great many times, as he did by building up a *pile* of metal discs. The cloth partitions were necessary to separate the sets, and the solution of salt acted to enable them to conduct the electricity along. Volta believed that the nerves and muscles of the frog merely acted as conductors, while Galvani thought they evolved the electrical action. Of the two discoverers, Galvani may claim to have discovered a new manifestation of electricity, and Volta to have pointed out in it a source of power of the utmost importance.

23. The electrical machine must next be noticed. The germ of this is seen in the piece of amber and the cloth which, by being rubbed together, first caused electricity to make itself known (chap. I.). An electrical machine is an arrangement for effecting the same object on a large scale. A glass cylinder (in one form), or a glass plate (in another form), is made to turn on an axis, so as continually to rub against a prepared silk rubber. When the friction is applied by turning the cylinder or plate, electrical equilibrium is disturbed—*positive* electricity collects on the glass, and the rubber becomes *negatively* charged—that is, as explained in chap. I. par. 13, the glass extracts electricity from the rubber.

When one body takes something from another, it seems natural to say that the former has a "charge," or holds in possession this something, though the latter cannot be said to be "charged" or in possession of it also. But in the case of electricity we may say that both are charged, one positively, or in excess, and the other negatively, or in "deficit," because in the case of both bodies *electrical action* results, which could not be till one gained what the other lost, and *vice versâ*. Now, the glass being a non-conductor of electricity, and it being necessary to have it collected that there may be a *combined* action, there must be a conducting reservoir, so to speak, on which to accumulate it as regularly as possible. This is done by placing a brass cylinder, mounted on a glass (*insulating*) stem, and the electricity is collected there while the friction supplies it. This is called the Prime Conductor.

24. From explanations in the last chapter it will be understood that, regarding all objects as having a natural quantity of electricity belonging to them, if the rubber and the glass were both *insulated* from the earth, the friction would soon exhaust all the electricity on the rubber, and a limit would be reached. To prevent this the rubber is brought by a *conducting* chain into communication with the earth, which acts as a *reservoir* of electricity. To prove that electricity has gathered on the Prime Conductor: apply the knuckle to it, when a spark will pass, and a smart shock can be given.

25. Thus electricity is produced both by friction and by chemical action—the same kind of electricity, but under different conditions. As regards proof of the existence of electrical action, it is not necessary that it should produce a spark or cause a shock. A little instrument called an Electroscope will determine the presence of very feeble electrical action. The simplest of all electroscopes is a pith ball suspended by a silk thread from an *insulating* support: a piece of glass rubbed on dry silk and applied near to it attracts and repels it, just as the amber in chap. I. An improvement is made by suspending two pith balls at one point of support; on presenting to them a *charged* conducting surface, they diverge. A pair of gold leaves is much more delicate if enclosed in an *insulating* glass cover, and attached to the end of a brass rod, with a knob on the

top passing through the lid. A very feeble charge of electricity on an object presented to the knob outside will cause the leaves to diverge.

26. To prove that the electricity of the friction machine and that of the galvanic battery is the same, all the effects which are produced by the one can also be produced by the other. Electricity from the machine can be made to pass in a current, but it is comparatively feeble. A galvanic battery can be made to produce a spark, but under ordinary circumstances it scarcely amounts to anything. Finally, when electricity in motion, or as a current, is required, the galvanic battery is incomparably superior; but when it is desired to observe electricity in a *static* form, that is, at rest, or not necessarily as a current, and, moreover, in its more powerful features, the electrical machine is the more convenient. The contrast between the qualities as produced by the two forms of *source* may be appreciated by the statement of the late Professor Faraday, who affirmed that a flash of lightning did not contain sufficient electricity to decompose one drop of water. Now this is a form of electrical action infinitely more powerful than that produecd by a machine, yet a very small battery indeed produces a current which decomposes water perfectly.

27. Electrical action is always accompanied by the development of heat, and in relation to the *conductivity* of metals, it should be stated that as they increase in temperature they offer greater *resistance* to the passage of a current. This fact has been beautifully employed by Dr. C. W. Siemens in the construction of thermometers for measuring the temperature of distant spots—such as the bottom of the sea, a ship's hold, a distant floor or sick ward, and places generally to which it would be impossible to penetrate for personal observation—since conducting wires can be arranged to lead from such places to any desired spot where results can be noted at leisure. The temperature of the distant spot is registered by the apparatus placed in any convenient room. For example: the captain of a ship carrying a

cargo peculiarly liable to combustion, wishes to know at any time, night or day, the temperature of the hold. The proper connections are arranged from the hold to his cabin, where is placed the registering apparatus. The other portion of the apparatus is kept in the hold. By passing a current through the circuits the captain can at any time discover by his registering index what the temperature of the hold is. It is a beautiful invention, and includes much more than is here said about it. The instrument is called a "Differential Voltameter"; this means a "Differential Measurer of Voltaic Currents," in which one current is *pitted*, as it were, against the other—just as in a pair of scales the principle lies in comparing one with the other.

28. The construction of the Voltameter depends on the fact that a current of electricity in passing through certain liquids (see chap. III. par. 37, 38) decomposes them, separating them into their original elements. Thus water is decomposed by a galvanic or voltaic current, and its oxygen and hydrogen gases are disengaged. The strength of the current is measured by the quantity of gas given off in a certain time. Moreover, the proportion of the combination forming water is two volumes of hydrogen for one of oxygen—or twice as much of the first as of the second—so when water is thus decomposed, there is always just twice as much hydrogen given off as there is of oxygen. The Voltameter was invented by Faraday, who gave to it the name of the great introducer of Voltaic Batteries.

29. There is no other *source* of electricity that sufficiently concerns the subject of telegraphy to claim further notice here, unless we except Atmospheric Electricity, and this is somewhat intimately connected with it, so much so that special precautions are sometimes employed in telegraph offices at home, and always with extra care in places abroad, to protect the instruments and coils, &c., the electricity being of such high potential as to be dangerous.

The word *potential* is more fully explained in chap. III., and is defined by comparison of different manifestations of electricity. It expresses a "power for" some effect or work, and a tendency to do it, as against some resisting effort.

CHAPTER III.

ON THE ACTION OF THE GALVANIC BATTERY—ELECTRO-MOTIVE FORCE—THE VOLTAIC CIRCUIT—GALVANIC OR VOLTAIC CURRENT—COURSE OF THE CURRENT—DIFFERENCE OF POTENTIAL CAUSING A CURRENT—EVIDENCE OF A FORCE—ELECTRIC CONDITIONS DEPENDENT ON CHEMICAL RELATIONS—EXAMPLES—BATTERY POLES.

30. The Galvanic or Voltaic Cell is the source from which is obtained the electrical action already pointed out as the prime mover or agent in the production of signals at distant stations. The quality or power which, it will be seen, causes motion in the magnetic needle, and gives new properties to a piece of soft iron, is necessarily described as a force, and is called *Electro-motive Force*, or, a motion-producing force derived from electricity.

31. This wonderful agency, so useful and so powerful, so trustworthy and docile, and so exact in its laws, working silently and with speed impossible to realise, has its birth, so to speak, in a little bath. Its evolution is accompanied by a series of chemical changes, in which the materials whence it proceeds are being dissolved into their original elements—being set free here, and combined there—so that every atom, as it were, of electricity that is produced is part of a beautiful process; and the little bath is a workshop wherein the elements of Nature are skilfully and unerringly working

in unceasing and regular order. The marvellous power, originating in the galvanic cell, causes the traces of its birth to be visible in the changes that have accompanied it, but goes invisibly about its work, and makes itself further known only by the wonders it achieves.

32. The Galvanic or Voltaic Cell consists of an insulating jar, in which are placed two plates or pieces of dissimilar metals, immersed in a liquid—the liquid must be composed of two or more chemical elements, one of which, at least, tends to combine with one or other of the metals, or *with both in different degrees.* A number of cells, beyond one, is termed a battery—a name, however, often applied to a single cell when working by itself.

33. When two metals—as, for instance, zinc and copper—are placed in water, slightly acidulated, without touching each other, no effect is apparent; but if they are made to touch, bubbles of hydrogen gas are formed over the copper plate, and continue forming there till the plates are separated. If, after being in contact for some time, the plates be examined, the copper is found unaltered in weight, but the zinc has lost weight, and the portion lost is found in the liquid in the form of sulphate of zinc. If the plates, instead of being made to touch, be joined by a conductor of electricity, as a copper wire, the same effects are produced: here we have a *Simple* Galvanic or Voltaic Circuit.

If any number of similar couples be arranged so that the copper of the first be joined by a conductor to the zinc of the second, and so on to the last zinc, we have a series of cells; and when the zinc of the first is made to join the copper of the last by a conductor, we have a *Compound* Galvanic or Voltaic Circuit.

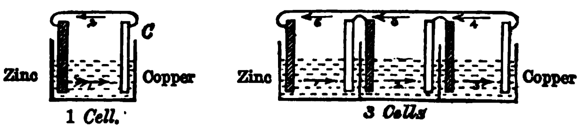
34. Where did the hydrogen gas come from, and what has forcibly taken away a portion of the zinc plate and compelled it to appear under another form? Further, how is it that until the terminal plates were joined nothing of all this was apparent?

The results are due to, or are consequent on, a current of electricity, and the laws of the electrical circuit (par. 13) governed their behaviour; for, until the terminals were joined, there was no complete circuit, and consequently no current of electricity could exist.

35. The diagrams in fig. 1 will serve to show the course of the current.

In the single cell the current of electricity flows in the liquid from the zinc to the copper, and from the exposed part of the copper by the conductor to the upper end of the zinc. In the compound circuit the current flows similarly from the first zinc and throughout the series of cells to the last copper, and thence by

Fig. 1.



the conductor to the zinc; in each case there is a complete circuit. Roughly speaking, the strength of the current, or quantity of electricity passing in a given time, is in proportion to the number of cells or pairs of plates.

36. The voltaic current makes its appearance under the general laws of electrical action.

We have said that electricity can be directly produced in various ways—amongst others by the contact of two dissimilar metals, as well as by the contact of a metal with a liquid. The electrical condition to which in any of such cases the bodies or materials are thus brought is most clearly expressed by saying that they are at a certain electrical *potential*. Regarding the earth as the great reservoir of electricity, its electrical state or *potential* is taken as zero; thus the potential of a body is the amount of its potential above or below that of the earth. In much the same way the level of any place is only its position above or below the surface of the earth, or above or below a mark which is taken as a standard.

When two bodies are at a different potential, electricity will flow from that which is the higher of the two (as to potential), to the lower *if they be connected together by a conductor.* Just as we know to be the case with water: if we join two reservoirs of water by a pipe, no flow takes place from one to the other if the surface in both is at the same level. If one be higher than the other water flows from it to the lower.

Now, since, when a metal is dipped into a liquid, electricity is produced, the liquid becomes of a different potential to the metal, each being electrified in an opposite way; and it follows, as above stated, that electricity will tend to flow from one to the other. This is evidence of a *force* being in action, for there can be no motion without some force to produce it.

[It must be remarked that whenever force is in action there must be an expenditure of *energy* to produce it. The disturbance of a state of rest *is* the manifestation of energy. Every effort, every change of any kind in the world of matter is manifestation of energy, and therefore energy infers change.]

Hence we say that an *electro-motive force* is set up, and it is this which plays the important part in the science of Electro-Telegraphy. We may call this the working power, as the pressure of steam is the working power which gives motion to the steam-engine.

37. But we must search further for the real source of power; a distinction is to be drawn between the mere "motion of electricity from a body at a certain potential to another body at a lower potential" and the "electro-motive force which accompanies or follows it." It is to *chemical action* that we finally trace the origin of the power employed.

The exact explanation of the process is still a matter of uncertainty, and its discussion would be beyond the limits of this little work. But it may be said generally that a difference of electric potentials in the metal and the liquid involves the transfer of electricity from one to the other—that is to say, a current flows—this chemically decomposes the liquid, and the reaction is the true source of power to which the resulting effects are due. It will be seen here that while we account for the expenditure of energy by saying that chemical action is the source of power, the preceding cause of this chemical action, namely, the transfer of electricity consequent on the difference of potentials of the materials, must also have first involved the expenditure of energy; and, in fact, the source of this power is uncertain.

38. To understand the action in the voltaic cell we must examine the chemical relations of the materials which it contains.

We have stated that the plates must be immersed in a liquid composed of two or more natural elements, one of which, at least, will combine with one or other of the metals, or both in a different degree. Those liquids which are thus decomposed by the passage of the electric current are called *Electrolytes.* The elements, then, forming the electrolyte may have chemical affinity for both metals, though in greater degree for one of them than for the other.

The element which is of the greatest importance in an electrolyte is oxygen, and according to the "affinity for oxygen of the metals used for the plates" is the magnitude of the effect resulting.

All metals have a definite relation to each other as to the electrical condition or potential which any one may have when brought into contact with another. It was explained in chap. I. that the opposite electrical condition of two bodies is expressed by saying that one is *positively* and the other *negatively* electrified. So when zinc is brought into contact with copper, the zinc has a potential positive to that of the copper—which further means, it will be remembered, that electricity tends to flow from the zinc to the copper.

The metals may be placed in a list so that each one would be positive to those, or any one of them, that follow it; it is said to be *electro-positive* to them, and they are *electro-negative* to it, or any that come before them in the list. Now those metals which are electro-positive to others have a greater affinity for oxygen, and those that are electro-negative to others have less affinity for oxygen; thus the terms electro-positive and electro-negative signify, in effect, greater and less affinity for this element. Conversely, oxygen will combine more readily with the former than with the latter.

39. Let us take a cell with zinc and copper plates.

Water is composed of oxygen and hydrogen in certain proportions. Considered as an electrolyte its element oxygen has affinity for both zinc and copper, but much greater affinity for zinc than for copper. (Therefore in the list just mentioned we should find zinc preceding copper.)

What then will happen? It is clear that, according to previous explanations, an electro-motive force will be originated at each metal, and these forces will act in opposition to each other, but the greater strength of the one will overcome the weaker, and the real power of the electric current will be the difference between the two. The battery plates are usually spoken of as the positive and negative elements.

The following list shows the commoner metals arranged in electro-chemical order, the arrow marking the direction of the current within the cell, indicating that it flows from positive to negative.

→

\+ Zinc. Lead. Tin. Iron. Antimony. Bismuth. Copper. Silver. Gold. −

In accordance with this list it is found that if in a galvanic cell zinc be coupled with a metal lower down on the scale than copper a more powerful electro-motive force is set up. A popular error may here be corrected. Persons uninstructed in the subject have thought that no galvanic cell could be constructed without zinc; but, strictly speaking, any two metals will serve if one have greater affinity for oxygen than the other. Still, zinc and copper are more generally employed.

40. It was said above that the zinc plate loses weight during the passage of the current, and it is perfectly well known what becomes of the portion thus taken from it; but the copper plate is not affected. The negative plate is, in fact, protected by the positive, and the truth is more plainly seen in the case of iron, which, when placed in muriatic acid, is readily corroded, but if a piece of zinc be also dipped in and brought into contact with the iron, the latter will remain unhurt till all the former is consumed.

A familiar illustration offers in the use of galvanised iron. Here is a body protected by a defender that will save it from destruction as long as its existence endures —that is, till the zinc is itself destroyed. This is done not by merely acting as a covering, but according to the law just mentioned. The iron, if left by itself, would soon be corroded by the oxygen in the atmosphere; but by associating zinc with it, we bring an electro-positive element into contact with an electro-negative, and, the former having greater affinity for oxygen, protects the iron while the zinc lasts.

Again, according to the list zinc is electro-positive to copper, and should protect it; and, in fact, Sir H. Davy found that a plate of zinc protected 150 times its own surface of copper when under water, as on a ship's bottom. The copper sheathing was thus spared, but unfortunately shell-fish and vegetable matter clung to it as being harmless, and so impeded the ship's speed.

41. The loss of the *Megæra* troopship will be remembered as having been caused by corrosion of the iron plates; and, no doubt, galvanic action was the primary cause. For, by the above law, iron is electro-positive to copper (and so also to brass, which contains copper), and these two elements would form the plates of a galvanic battery, the liquid or electrolyte being

the sea water. The metals were in some way practically brought into contact, and the positive iron protected the negative copper, being itself gradually destroyed in the process.

42. A galvanic battery is said to have two poles—a positive and a negative—which are in fact the terminations of the plates. It is necessary to bear in mind that the current always leaves the battery by the positive pole; and to understand the matter more clearly the current must be considered in a two-fold aspect, namely, as being partly *within* the battery and partly *without* (see diagram 1). *Within*, it leaves the positive element (or plate) and passes to the negative element, but *outside* the cell (or, as it were, on its return path) it leaves the positive *pole* and goes to the negative *pole*. The starting point in each portion of the journey is positive, and thus the copper is the negative *element*, but the positive *pole*, because the current *leaves* the battery by it—and the zinc is the positive *element* because the current begins there *within* the cell, and the negative *pole* because it ends there outside. The positive pole is the terminal of the negative element and *vice versâ*.

The liquid or electrolyte acts as a conductor within the battery, and the conductor outside, or, in practice, the telegraph wire, and the earth connection completes the circuit.

43. There is but one current from a battery, namely, a positive one; what is called a negative current is merely the positive current passing in the reverse direction from the same pole, that is, the positive pole.

It is usual in speaking of the current to leave out of view the fact of its existence and commencement inside the battery, and to treat it as if it actually originated at the pole.

CHAPTER IV.

SINGLE AND DOUBLE-FLUID CELL—CHEMICAL ACTION IN SINGLE-FLUID CELL — INCONSTANCY OF CURRENT—DANIELL'S CONSTANT CELL—CHEMICAL ACTION OF DITTO—VARIOUS KINDS OF CELL.

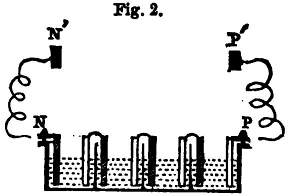
44. Galvanic batteries may be divided into single-fluid and double-fluid batteries.

45. The single-fluid cell, the simplest form of cell practically in use, consists of a plate of zinc and a plate of copper immersed in water slightly acidulated by the addition of a little sulphuric acid. In a battery of several cells the zincs and coppers are generally soldered in pairs and placed in a long stoneware or glass trough, divided into separate cells by partitions, as in fig. 2.

This battery is made more portable by filling the cells with sand, which supports the plates and prevents the liquid from splashing about when the trough is moved. In this form it is called the common sand battery.

46. The poles of the battery were in chap. III. spoken of as the terminations of the plates. In the diagram (fig. 2) the points N and P are actually the terminations of the plates, each plate being terminated there, and carrying a screw to which any conductor can be joined. But suppose there are two points, N' and P', to which a conductor may lead from these screws; these points might be the terminal screws connected to a signalling instrument, and they may be conveniently called the poles of the battery if desired. It is just a matter of arrangement.

Fig. 2.



47. Of course when used in telegraphy half of the conductor joining the two poles is really the telegraph

wire, which may be many miles in length; and this together with the earth portion from one station to the other makes up the *circuit*.

48. The following process goes on in the single-fluid cell when the circuit is completed—that is, when the battery is set to work.

While the current flows through, the water is decomposed and oxide of zinc formed. The oxygen of the water has greater affinity for the zinc and leaves the hydrogen. (Water being composed of hydrogen and oxygen, in chemical symbols H_2O.) The zinc is being consumed during the process, as coal is consumed when it burns while combining with the oxygen of the atmosphere. This oxide of zinc unites with the sulphuric acid to make sulphate of zinc, and this salt is found to accumulate in solution in the liquid of the cell. At the same time the hydrogen of the water goes to the negative or copper plate and gathers over it in little bubbles.

49. The current of electricity passes out from the positive or copper *pole*, completing its circuit as set forth in chap. I. The poles are also called *electrodes*, signifying "ways" or paths for the electricity.

50. The process thus described as going on in the cell will be better seen from the accompanying figure or plan of the chemical decomposition and recombinations.

ACTION IN THE VOLTAIC CELL (SINGLE FLUID).

Sulphuric Acid	}	Found at Positive plate, Sulphate of Zinc.
Zinc } Oxide of Zinc	}	
Water, Composed of { Oxygen } (with Zinc)		
and		
Hydrogen		At Negative plate, Hydrogen.

51. This kind of battery is not at all constant in its action; that is to say, the current is constantly and increasingly being checked and opposed by the action of the elements which through chemical decomposition were set free. The hydrogen gathers over the surface of the copper plate, and an *electro-motive force* is set up (par. 30), which counteracts the electro-motive force

producing the current—the copper plate is said to be *polarised*. By the bubbles of hydrogen adhering to the plate the surface in contact with the liquid is decreased, thus the plate is practically smaller, and a single-fluid battery which at starting gave a good current very soon shows that it is really weakened. The consequence is that zinc is consumed extravagantly, as well as acid, and the battery is working to a great degree without useful results; moreover its *resistance* constantly increases. With regard to this point it must be mentioned that liquids being very bad conductors of electricity, a great part of the ordinary *resistance* in a battery arises from this cause. The addition of acid improves the conductivity, and, as the sulphuric acid is gradually used up, forming sulphate of zinc with the oxide (see figure), the resistance necessarily increases.

The sand battery is the worst of all batteries as regards electro-motive force, because the gas cannot escape readily, and *polarises* the copper more persistently.

52. To obviate these difficulties it was necessary to construct a cell with such arrangements that the hydrogen should not remain *disengaged* to work this mischief, and the remedy was found in what is known as "Daniell's Constant Cell," from Professor Daniell, who invented it. This is a double-fluid cell, there being two separate liquids. Of this kind of cell many forms are in use, but the principle is the same throughout. There is a positive and a negative element, and the cell is divided into two receptacles for the two fluids. The original "Daniell" is arranged as follows. In the containing vessel is a perforated copper, which forms also the negative element (or plate). Inside this is another vessel of porous unglazed earthenware, containing a cylinder or a rod of zinc. This is the positive element. The space between the copper and the porous cell is filled with a solution of sulphate of copper kept *saturated* * by

* A solution is said to be *saturated* when the liquid has dissolved as much of the substance as it can, and will dissolve no more. Salt thrown into water will melt till, after a certain quantity is dissolved, the rest will remain unmelted.

the addition of crystals of this salt lying on a shelf, and dilute sulphuric acid is placed in the porous cell round the zinc. More often now the copper and zinc change places in this form, the outer vessel being generally of zinc and the rod in the porous cell being of copper—the solutions also change places. Strips of copper are used for joining up the zinc and copper poles as required. The action in the cell is explained below, the various forms generally in use being first considered.

Take the following description of three Daniell's cells arranged in a form used in telegraphy. A glass trough has glass partitions, which separate it into distinct cells insulated from one another. In these cells stand porous earthenware pots, containing a *saturated* solution of sulphate of copper, and outside of them is placed a solution of sulphate of zinc. Thick plates of zinc are joined by connecting-bands to thin plates of copper, and are so arranged that the coppers stand in the porous cells, and the zincs in the sulphate of zinc. The terminal plate of copper forms the positive pole of the battery, and the terminal zinc has a copper wire soldered to it, which forms the negative pole.

In one common form, called Muirhead's, the glass trough contains ten cells, which stand inside a teak case with a lid through which gutta-percha covered wires pass at the ends. Crystals of sulphate of copper of the size of a hazel-nut are placed in the porous cells to maintain the solution in a saturated condition. The copper connecting strap is cast in the zinc, having been tinned to ensure adhesion. The zinc plates may be four inches long and two wide, and the copper plates about four inches square. The zinc should hang on the upper part of the cell and not reach to the bottom.*

58. Besides the improved arrangement of the materials of this form of battery there is an advantage in placing solution of sulphate of zinc round the zinc element instead of dilute sulphuric acid, as we described in the first mentioned Daniell. In that particular

* Jenkin's "Electricity."

arrangement the sulphuric acid would gradually have formed sulphate of zinc at the expense of the zinc plate, even when the battery was not in use, but in the last described no such action can take place.

54. The chemical action in this form of Daniell is as follows:—

As in the single-fluid cell, so here, the water is decomposed and the oxygen combining with the zinc forms oxide of zinc, and this with the sulphuric acid forms sulphate of zinc. The hydrogen of the water by means of the peculiar power belonging to it, in what is called its *nascent** state, of separating metals from their solutions, decomposes the sulphate of copper leaving oxide of copper, and again separates this into oxygen and copper. The oxygen then combines with the hydrogen and water is formed, and the copper is thrown on to the negative or copper plate. Thus the hydrogen after doing its work is got rid of, and just as much water is formed as was decomposed at first.

The porous cell prevents the liquids from mingling together, but allows the hydrogen to penetrate its sides and so gain access to the sulphate of copper.

55. A plan of the process is given here as in the case of the single-fluid cell. This will serve as a guide to the action in other forms of Daniell's battery.

ACTION IN THE DANIELL (DOUBLE-FLUID) CELL.

Zinc................................. }		Oxide of Zinc... }		Found at Positive plate, Sulphate of Zinc.
Water...... {	Oxygen............ }			
	Hydrogen..................................		... }	Water.
Sulphate of Copper {	Sulphuric Acid..............			
	Oxide of Copper {	Oxygen...... }		At Negative plate,
		Copper		Copper.

The brackets in each case enclose the elements or compounds which make up the substance pointed out

* This word, from the Latin, meaning "being born," is used to express the "period of birth" of a substance. The "nascent" state is its condition while being produced.

by the *loop* of each bracket. Thus, water, composed of oxygen and hydrogen. Oxide of zinc, composed of zinc and oxygen. Sulphate of copper, composed of sulphuric acid and oxide of copper, which latter again is composed of oxygen and copper. Sulphate of zinc, of oxide of zinc and sulphuric acid, and so on.

56. Other forms of double fluid cell are "Grove's" and "Bunsen's." "Grove's" cell is very powerful in its action, but objectionable on the ground of expense at first cost and the employment of nitric acid, the fumes from which, while chemical action is going on, are very injurious.

57. "Bunsen's" cell is very much the same except that the negative element is neither copper nor platinum, but *carbon.* The fine coke-dust or scrapings from the roof of gas retorts in which coke has been made, is pressed together in a mould and soaked in gas-tar till it acquires the necessary solidity.

These two, Grove's and Bunsen's cells, are not generally used for telegraphic purposes.

58. A modification of Daniell's cell much used in France, and well adapted in some respects for telegraphy, is that known as "Callaud's" cell; also called a *Gravity* battery, the liquids being simply prevented from mixing by the law of gravity forbidding the heavier of the two from rising through the lighter.

In this arrangement a thin plate of copper is laid on the bottom of an earthenware or good *insulating* jar, having an *insulated* wire or strap leading up the side. On this plate are laid crystals of sulphate of copper. A solution of sulphate of zinc is then poured in, and on the top is fitted a zinc plate, forming the positive element. The vessel must not be shaken, or the sulphate of copper when dissolving will mix with the solution above it.

59. There are many varieties of this kind of cell, in which no porous cell is required. A glass tube is sometimes placed in the middle, reaching to the bottom, through which crystals of sulphate of copper can be dropped.

60. A very convenient form of cell without a porous jar is called "Minotto's," from the inventor (as is also the case with "Calland's"). The cell is here filled with sand moistened with dilute sulphuric acid, placed on the top of the crystals of sulphate of copper. When the cell is in action, sulphate of zinc is produced. This form is very portable, and is often made in sets of, say ten, in a single insulating trough with ten partitions.

61. Another form of battery preferred by many telegraphists abroad is called, from its inventor, the "Marié-Davy." The elements are a zinc cylinder and carbon rod, and sulphate of mercury is placed round the carbon in a porous cell.

62. We shall notice one more form of cell, and this is one very well adapted for telegraphic requirements; it is called, from its inventor, the "Léclanché." The outer glass jar contains a rod or "prism" of zinc immersed in a solution of *sal-ammoniac* and forming the *positive element*. In the middle of this glass jar is also placed a porous cell containing a rod or prism of *carbon* surrounded closely by a pounded mixture of *peroxide of manganese* and carbon. The carbon rod is the *negative element*. These cells are made very portable, and if a little water be sometimes added, they will remain perfectly good for twelve months when once set up. One great advantage is, that there is no "*local action*" in them. This means that there is no chemical decomposition going on in the cell, unless the *circuit* is *closed*. Other batteries have always more or less of this action "to waste," even while the poles are not joined by a conductor; but in the Léclanché there is no waste, and until properly "set to work," there is no action going on within.

63. A battery suitable for the telegraph should not fail in its energy to an appreciable extent for five or six months. The Léclanché is superior to others, in the fact that it maintains its qualities longer if kept constantly in action.

There is a number of other varieties of battery, but those considered here are most applicable to telegraphy.

CHAPTER V.

MANAGEMENT OF BATTERIES—DIVISION OF RESISTANCE—CONDITIONS GOVERNING STRENGTH OF CURRENT—OHM'S LAW—REGULATION OF ELEMENTS AS TO SIZE OR NUMBER—COMPARISON OF VARIOUS KINDS OF BATTERY—DEFECTS TO BE LOOKED FOR—CAUTIONS FOR KEEPING IN ORDER.

64. To enable a telegraph operator to manage a battery to the best advantage he should thoroughly understand the principles at work, and should know what its qualities as a good or bad battery depend on, and what are the difficulties to overcome.

65. There is one important item to consider, and may be divided generally into *external* and *internal* that is the *resistance* existing in the circuit. This resistance. The *external* resistance in practice is that which exists in the conducting line and the various instruments connected with it. The *internal* resistance is that belonging to the battery itself; we are chiefly concerned with this latter resistance at present.

66. On the other hand, the actual power of the battery is dependent on the electro-motive force (par. 30), and this depends generally on the number of elements or couples of plates in a series; thus there would be a greater electro-motive force in a battery of six cells than in one of three similar cells—it would be double. The electro-motive force does not depend on the *size* of the plates, so that a small plate affords as much of this force as a similar one double the size.

67. The *resistance* of a battery, on the contrary, *does* depend (partly) on the size of the plates, inasmnch as a large plate offers less resistance than a small one.

It depends also on the distance between the plates and on the solutions employed.

68. What, now, is the *resistance* spoken of? It is resistance to the passage of a current, opposition or resistance to *conduction*. This we formerly stated to be (par. 16) *directly* proportional to the length and *inversely* proportional to the sectional area of the conductor. The conductor to be considered here (for any one cell) is the surface of the plate in the liquid and the thickness, literally length, of the liquid separating the plates. According to the rule (par. 16), the longer the distance between the plates the greater the resistance, and *vice versâ;* and the larger the surface of the plate the less the resistance.

69. Now, on the electro-motive force and the resistance depends the strength of the current or quantity of electricity passing in a given time, and the quality of a battery in this respect will be determined by the arrangements as to number of cells and dimensions of surface for contact of plates and liquid.

70. The operator has the choice of two methods of arranging his battery: he may either add cell to cell in a series, or he may practically increase the size of his plates by joining them in "pairs" or "threes," and so on. That is, connecting together the copper plates of 2, or 3 cells, and the same with the zincs, and thus making a double, or triple arrangement. The action depends on the considerations above discussed in regard to electro-motive force and resistance.

71. The law governing the strength of the current is defined comprehensively by the formula known as "Ohm's Law," which can only be satisfactorily considered by expressing it mathematically. Calling the current C, electro-motive force E, and resistance R, the expression is $C = \frac{E}{R}$. In words this means that the strength of the current is directly proportional to the electro-motive force of the battery, and *inversely* proportional to the resistance of the circuit. This sums up

the general statement that C will be greater or less as E is greater or less, but will be less when R is greater and greater when R is less.

72. But we must not forget that although E exists only in the battery, the resistance exists not only there, but throughout the circuit. If the battery poles were joined by a short, thick conductor, presenting practically *no resistance*, both E and R would be on equal terms—in this way, that no change in the strength of the current could be made by adding any number of cells. A thousand cells would give no stronger current than a single one, because, though there would be 999 additional sources of electro-motive force, they would also bring 999 additional amounts of resistance. If $C = \frac{E}{R}$ its value remains just the same if we increase E and R equally; for $\frac{1000\ E}{1000\ R}$ amounts to the same thing.

73. From this we establish the fact that, dividing the resistance of a circuit into *external* and *internal*, if there be no external resistance we cannot increase the battery power by adding cells in single series. On the other hand, if we increase the size of the plates under such circumstances, the resistance will be decreased in proportion; and according to the rule, the strength of the current is increased, for the electro-motive force remains as before, but with *less* resistance. It follows, therefore, that the relation of the *external* resistance to the internal resistance of a circuit regulates the arrangement of a battery.

74. The smaller the external resistance is *compared with* the *internal* or battery resistance, the less will the current be affected by increasing the number only of cells, but the more it will be increased by enlarging the plates. Again, if the *external* resistance is large compared with the battery resistance, an increase in number of cells affords a greater strength of current.

75. The above ratio $\frac{E}{R}$, when the external resistance is considered separately from the internal, must be con-

verted thus: calling the former r and the latter R, the expression becomes $C = \frac{E}{R+r}$.

As regards a telegraph circuit, it must be remembered that when we increase E by adding more cells, we also increase R, but do not alter r; and if we increase the size of the plates, we do not alter E nor r, but decrease R. The expression $C = \frac{E}{R+r}$ may be summed up as stating that "the strength of a current depends on the ratio between the electro-motive force and the several resistances in the circuit."

76. A battery of (say) twelve cells could be arranged either as twelve single cells, six double cells, four treble cells, three quadruple cells, two six-fold cells, or a single twelve-fold cell; and knowing the resistance of one cell, the calculation could easily be made as to decrease of resistance in each case.

77. The strength of the current in the working of a line of telegraph is chosen with reference to the effect on the signalling instrument at other stations. In the early history of telegraphy the manager of a line encountered a difficulty which he could not overcome by his own unaided knowledge; in fact, he could not obtain an effective current from his battery, and his signals were unintelligible at the receiving end. He informed the manager of another line of the case, and stated that he had increased the number of cells in his battery, but with no benefit. His friend replied that it was strange, but that he himself had found on his line that an increase in the number of cells improved his signals. He added, however, that he had previously thought of enlarging the dimensions of the elements by coupling the similar poles, and recommended the experiment, as the two lines appeared to be unlike each other. The advice was followed with success, and a little examination of Ohm's Law, as worked by figures, will explain the reason very plainly. The fact probably was, that the first manager's line was short; at all events, the external resistance was small in proportion to the internal;

and in the case of the second line, the conditions were reversed.

78. Let us assign an imaginary value to each letter in the expression $\frac{E}{R+r}$.* Let E=900, R 80, r 10. This is to represent the conditions of the line of the first manager. Then $C=\frac{E}{R+r}$ becomes $C=\frac{900}{80+10}$ or 10 (1). Now suppose he doubled the *number* of his cells. Then E will become 1,800, R 160, and r remain 10, because the electro-motive force is doubled, and the *interior* resistance also, but the exterior resistance is not affected. This gives $C=\frac{1800}{160+10}=\frac{1800}{170}=10{\cdot}588$ (2). Comparing this with (1) we see there is no gain to speak of, though he used twenty cells where he only used ten at first.

But suppose he doubled the *size* of the elements instead of doubling the number. Then E=900, because the electro-motive force is unaltered, but R=40, the interior resistance being *halved*, and r=10. Therefore $C=\frac{900}{40+10}=18$ (3). The effect compared with (1) or (2) is nearly doubled.

79. The other case, when the *external* resistance is large compared with the *internal* may be taken thus: E=900, R=10, but r=80, reversing the amounts. Then $C=\frac{900}{10+80}=10$. But, doubling the number of cells, $C=\frac{1800}{20+80}=18$, nearly double. And suppose, instead, the *size* of the plates were doubled, then $C=\frac{900}{5+80}=10{\cdot}588$, or no appreciable gain.

The figures here employed are merely chosen for convenience of illustration. In practice the resistances would be very different as to values. But the rule is strictly true, and may be proved by experiment with a battery and *galvanometer*, or instrument for measuring the strength of a current. (Chap. XIV.)

* R is the *internal*, and r the *external*, resistance.

80. The following results are recorded to show the comparative values of the different batteries referred to—the observations were continued for a considerable time, and may be relied on for accuracy.

The electromotive forces of these batteries are in about the following proportions :—

Taking	"Groves" . .	at 100
„	Marié Davy .	76
„	Léclanché . .	82
„	Callaud . . .	56
„	Daniell . . .	56

Signifying that a "Grove" cell has the same strength, or will produce, on a Galvanometer (par. 238), the same deflection in a circuit 100 miles long as a Marié Davy on one 76 miles long, and so on.

As to constancy of action :—

"*Marié Davy.*"

The electro-motive force fell 1/40th of its value in five months on an *open* circuit. The current is always irregular in a *closed* circuit (meaning that when at work its action is irregular). In practice, with weak line resistance and short circuit, its electro-motive force diminishes very rapidly, but will recover its strength partially if the circuit be kept *open* for some time. It *polarises* rapidly, that is, the current is weakened by "local action" (par. 62) and gas bubbles on the surface of the plates.

"*Léclanché.*"

The same disadvantage as regards loss of strength. Its electro-motive force falls rapidly on short circuit and with weak resistance. With higher line resistance it works well.

"*Callaud.*"

This cell acts very much the same with *closed* and *open* circuit. That is to say, its electro-motive force will, if tested either after working, or after rest, prove nearly the same.

As regards internal resistance, the "Daniell" is the highest, then "Marié Davy," then "Callaud," and least of all "Léclanché,"—the proportions being 8½, 6, 5½, and 4. The "Callaud" is preferred to the others for its constancy and endurance.

81. The larger sized cells give the most constant and

regular current. "Marié Davy's" is not fitted for good telegraph service. On all grounds, including that of economy, "Callaud's" is recommended as the most serviceable.

82. The following defects should be looked for when it appears that the current is deficient. We give almost the words of Professor Jenkin on the subject:—

1. Solutions exhausted. For instance, when in a Daniell's cell the solution is colourless, showing that the sulphate of copper is gone, or nearly so.

2. Terminals or connections between cells corroded, so that, instead of metallic contacts, we have *oxides* of almost *insulating* resistance intervening in the circuit.

3. Cells empty or nearly empty.

4. Filaments of deposited metals stretching from *electrode* to *electrode* (par. 49).

Intermittent currents are sometimes caused by loose wires or a broken electrode, which makes and breaks contact when shaken, and the shaking of a battery will sometimes produce an inconstant current.

83. The batteries should always be kept in the best condition for work, each cell being thoroughly insulated, and the floors and tables in the battery-room kept scrupulously clean and dry, so as to prevent the least leakage or escape of the current.

In a Daniell's cell the solutions should be inspected daily, and crystals of sulphate of copper added as required, and sulphate of zinc removed. No sulphate of zinc or dirt should be allowed to collect at the lips of the cells. The zinc plate must not touch the porous cell, or copper will be deposited upon it (the zinc). The battery should be charged with sulphate of zinc from the first. The plates should be clean. Porous cells should be examined and cracked ones removed. The copper solution will, unless watched and prevented, rise over the edge of the porous jar; the tendency of such solutions being to mix with each other by an action called *osmosis*. These directions will apply generally to all forms of batteries.

CHAPTER VI.

APPLIANCES TO MAKE UP A LAND TELEGRAPH LINE—WIRE EMPLOYED—POLES TO UPHOLD WIRE—INSULATORS—JOINTS.

84. The study of Electro-Telegraphy is so mixed up with various sciences that some considerable ground must always be gone over before the application of these sciences can be made intelligible. We have considered, first Electricity, then its sources, especially that most used in telegraphy, next the Galvanic Battery and the origin of the Voltaic Current, which is the grand agent in the production of signals. The application of the current should follow next in order, but, previous to entering on this, we have to mention some other appliances which go to make up a line of telegraph.

85. The motive power or the current of electricity originates in the battery, and travels along the conducting wires to the distant station where it produces the required signals by means of instruments prepared to be influenced by it. Thence by means of earth plates (par. 14) it returns to the place of starting. The wires, the *insulators* (par. 15), and the supports will be briefly treated of here, after which the means of applying the electric current will immediately follow.

86. The wires used in a land telegraph line are generally about 1-6th inch diameter. They should be galvanised (par. 40), and each should be capable of being bent round itself and unbent without injury.

It should also stand bending four times, first one way and then the other to a right angle, being held in a vice. It is stretched 2 per cent. (two inches in every hundred) when cold before using. This process is called *killing;* it prevents springiness when stretched between the poles. It should be painted or varnished in smoky localities.

87. From 15 to 20 poles to the mile is usual on

straight lines, but on sharp curves as many as 40 per mile are required. Where several wires are supported on one pole they should be not less than 12 inches apart vertically, or 16 inches apart horizontally.

88. The poles, used only to support the wires, are generally of larch impregnated with creosote or oil of tar. The ends in the ground are charred and baked to preserve them. They should be painted above ground. The wire is not fastened directly to the poles, but to the *insulators*, which are firmly bolted to them. The poles are thus separated from the wire so as to cut off communication with the earth. Still, at every pole there must be some communication with the earth even when the wire is separated from it by the best *insulators*.

89. For these glass does not answer very well because it becomes covered with a film of moisture in damp weather, and the leakage of the current is largely encouraged by these conditions; that is, it will pass from point to point of the surface till it reaches the wood. Porcelain makes good *insulators*, for rain will run off it easily, and being glazed its insulation is improved.

Brown stoneware is an excellent *insulator*, and is also cheap. There is also an advantage in the fact that insects which often collect on an insulator and cause loss of insulation by dirt, spiders' webs set there to catch them, &c., do not trouble the stoneware.

The form generally chosen is that of a bell, or of several bells inside each other. This latter form is used to decrease the chances of leakage, since the current to escape must run down outside and up inside each one successively.

It is desirable to expose one surface to rain that dust may be washed off, &c., and to protect at the same time another portion from wet, that if the outside do not insulate the inside may.

Before leaving the factory where they are made insulators are carefully tested for *insulation*, and any that show signs of allowing a current to pass through the material are rejected.

90. In cases where several wires are supported on one pole, a current when passing on any one is apt to cross to the others and thus confuse the signals at the place of reception. To remedy this a wire from earth is led up the pole and across every portion of it by which electricity could be conducted from one insulator to another. Any leakage thus goes direct to earth, and though it weakens the received current, yet it prevents the confusion which the cross travelling from wire to wire would make.

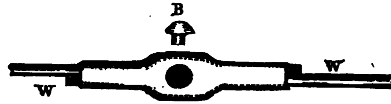
91. As the wire can only be delivered in limited lengths it must be joined at many places in a telegraph line. These joints are sometimes the cause of much trouble. The object in making a joint is to render it as perfectly *conductive* as possible, and to prevent it from loosening. Various joints have been devised, of which we give two specimens. The best of all is considered to be the "Britannia joint"; in this form (see diagram)

Fig. 3.

the wires are laid back to back, the ends turned over as represented; it is then wrapped with fine wire and soldered over. No joint surpasses this for strength and constancy, also for ensuring perfect *continuity* for conducting the current.

92. A joint used in some land lines abroad, patented by Siemens Brothers, is represented in diagram. The wires are laid side by side within the sheath *S*, and a little bolt *B* is smartly tapped through the hóle *H*; in passing between the wires it presses them

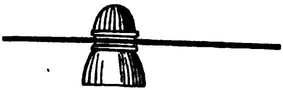
Fig. 4.



tightly against the inside of the sheath. It is then wrapped over with wire and soldered. In all cases telegraph joints that are intended to be permanent must be soldered.

93. There are various methods of fastening the wire to the insulator. The ordinary way, as seen about London, is to attach it as shown in diagram 5, binding it with fine wire well fastened. As little as possible of the surfaces are brought in contact.

Fig. 5.



In order to utilise the electric current it is necessary to call in the assistance of a power generally believed to be a totally distinct one, though it can be proved that this opinion is without foundation. This power is known as Magnetism.

CHAPTER VII.

MAGNETISM A CONDITION OF ELECTRICAL ACTION—NATURAL AND ARTIFICIAL MAGNETS—POLARITY—EARTH'S DIRECTIVE ACTION—ARMATURE—THE EARTH A GIGANTIC MAGNET—CONDITIONS ON WHICH THE VARIOUS FORMS OF TELEGRAPHIC INSTRUMENTS DEPEND—ELECTRIC CURRENT DEFLECTING MAGNETIC NEEDLE — SINGLE NEEDLE ALPHABET—DEFLECTION ACCORDING TO COURSE OF CURRENT—RULES FOR DITTO—ASTATIC MAGNET—VARIATION AND INCLINATION.

94. Electricity and magnetism are now known to be so intimately connected that they are no longer considered as subjects of separate sciences.

Magnetism in a body is believed to be a peculiar condition caused by electrical action. Both electricity and magnetism have the power of communicating their peculiar properties to other bodies without being in contact with them; as the expression is, *inducing* the power, which becomes insensible when the bodies are placed very far apart.

95. Every one has heard of the loadstone and its remarkable property of attracting iron and of pointing towards the north. This peculiar iron ore is a *natural* magnet; artificial magnets used, before the production of magnetism by electricity was discovered, to receive their magnetism by being rubbed with a loadstone, or, more commonly, with other artificial magnets. These are merely bars or rods of tempered steel which thus derive their magnetic qualities. The word "magnet" is taken from the country of Magnesia, where the loadstone was first discovered.

96. Every magnet has what is called *polarity*, that is, each end of it is a separate pole. By this term we are to understand that the body to which it is applied is marked by two distinct and opposite features or qualities. Every body has two ends, but an object can only be said to have two *poles* if the end possess opposite characters, so that one could never be mistaken for the other. The attractive power of a magnet is situated almost entirely in the poles, but there is this further remarkable fact about it that, if it be cut up into any number of pieces, each separate piece has two poles, and is therefore a separate magnet. They are called *north* and *south* poles; in England the poles are not named as they are in France. A magnetised steel needle if pivoted on an upright point or suspended from its centre by a string will fix itself pointing north and south: we call the north pole that which points to the north and *vice versâ*, but the French reverse the names.

97. The reason of this difference is taken from the theory that the earth is a vast magnet, and, of course, the names of its poles are unalterably fixed. Now, a magnet attracts unmagnetised iron or steel equally with either pole, but the action of one magnet on another is

different. The north pole of a magnet attracts the south pole of another magnet, and *vice versâ*, but repels a pole of its own name. Therefore if the earth be a magnet, it would really be the *south* pole of the magnetic needle which turns to the north; and in fact the French south pole in a magnet is our north.

98. The magnetic needle seldom points to *true* north and south. The imaginary line, north and south, called the *astronomical meridian* is rarely in accordance with that joining the magnetic poles or *magnetic meridian.* When steering a ship by a compass (which is a pivoted magnetic needle) this deviation must be taken into account; it is called the *variation.*

99. The magnetic power of the earth perpetually forces the magnetic needle, when free to move, to take a certain position; this influence is simply *directive*, a word implying something different from attraction. It means that this power regulates the *direction* to be taken by the poles of the magnet; it does not cause the whole to move bodily towards the north or south. We all remember playing with little toy swans in a basin of water, and attracting them to the side by a magnet held in the hand; they had another magnet concealed in the body. In this case the swan would place himself pointing north and south if we removed the hand, and would so remain. The question arises, "Why does he come from the centre of the basin to the side when we present our little magnet to him, and does not do so if he is acted on by the great earth magnet?" It is not because he cannot pass through the side, for if such an object could be placed in a canal of water reaching to the earth's pole itself it would still be unmoved. The reason is that the little magnet in the swan is infinitely small compared with the distance between *either* of its poles and the pole of the earth. In fact, the north and south poles of the swan are practically at equal distances from the earth's pole, and one pole is repelled just as much as the other

is attracted. Otherwise it might swim away up the canal instead of merely *pointing* towards the north.

100. A piece of steel when magnetised is called a permanent magnet because it retains its magnetism for a long time, but soft iron cannot be permanently magnetised. A piece of soft iron may be made to hang to the end of a magnet by mere contact and becomes magnetic; if now its lower end be dipped into iron filings (while still hanging), they cleave to it. When it is detached, its magnetism disappears and the filings drop off. It may also be temporarily but more feebly magnetised without being in actual contact; in this case its acquired power of attraction depends on the power of the magnet and the distance at which it is placed from it, and the magnet is said to have *induced* magnetic power in the iron.

A magnet can attract an object such as a magnetic needle though the two are separated by some intervening body. A piece of soft iron called an *Armature* is placed across the poles to preserve the magnetic power, which becomes weaker if they are not covered in this way. The little horse-shoe magnets sold in the toy shops all have their armatures.

101. A steel poker can be magnetised by holding it in a certain sloping position for a little while and giving a few blows with a hammer at the top. Workmen often find their tools to be magnetic; and pieces of iron, if left in one place for any length of time, are discovered to have the powers of magnets. All this is a strong proof that the earth is itself a gigantic magnet and *induces* these magnetical properties.

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102. It will be seen that magnetism divides the palm with electricity in respect of its services in Electro-Telegraphy.

103. All forms of electro-telegraphic instruments depend on one or other of the following conditions, and chiefly on the first two :—

I. The power of the electric current to deflect a pivoted or suspended magnetic needle or bar from its position of rest, and throw it in another direction.

II. Its power to make soft iron temporarily magnetic, the magnetism deserting the iron on the stoppage of the current; and, further, the property of rendering temporarily magnetic a conducting wire arranged as a coil.

III. The Power of the electric current to produce chemical decomposition of certain substances.

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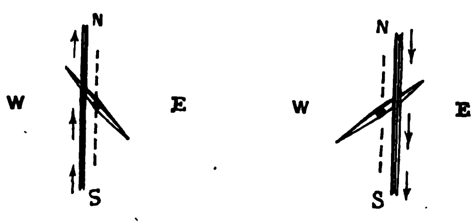
104. A magnetic bar or needle pivoted on its centre will, as we know, point north and south. If an electric current is in action along a wire placed parallel to and either over or under the magnetic needle, the latter will be turned from its position and will remain out of its proper direction so long as the current continues. On the current ceasing it regains its true position. The needle can be turned east or west according to the direction and course of the current. The arrows show

Fig. 6.



the course of a current through a conducting wire parallel to a pivoted magnetic needle. In the one case the course is from south to north, and in the other from north to south.

It is thus that an operator at a station A can cause a magnetic needle at B, say, 100 miles distant, to move right or left at will, provided he is in "conductive communication" with B, and can send an electric current throughout the circuit. He has his source of electricity properly connected as part of the circuit; and by starting the current either through the conductor or through the earth (see par. 14) as may be required he sends it round the needle in either direction, and the operator at B who is watching notes the movements.

105. The current is so docile that it acts instantaneously—there is no *gradual* commencement and cessation—it begins at once and ceases at once; so that a tap of the finger on the key or starting apparatus at A causes the needle at B to make a jerk, right or left as may be required, at the same instant. In fact, the movement of the fingers at A and the corresponding deflexions of the needle at B would be seen to be simultaneous if it were possible to have both under view at once.

106. Here then are *two* distinct movements or signals which can be infallibly produced by a person who controls an electrical current in circuit with the magnetic needle. Now, if there were only *two* letters in the alphabet there would be a separate signal for each letter, but as intelligible communication by such means must depend on the power to indicate particular letters, and since there are 26 letters in the alphabet, some way must be found to enable us out of *two* movements to produce twenty-six clear and separate arrangements. To explain a little more fully; the only kind of signal that a current of electricity can produce on a magnetic needle is at best but a movement, and the utmost that such a signal can represent is one letter of the alphabet. It is true it might be made arbitrarily to represent a word, but this is but a combination of certain letters. Now if a current of electricity could make twenty-six distinct and different signals an alphabet would be made, that is to say, the foundation of language. But as one signal only at a time can be produced, and a wire can only represent one letter, twenty-six conducting wires would be necessary; and by sending the current in succession along the right wires words could be conveyed piecemeal,

since each wire would belong to a separate letter. It is practically impossible to have so many wires, and thus we must be content with using one and see how many distinct movements can be made with its help. A current of electricity can pass in the two opposite directions along this wire and make two different movements and two only. It is therefore necessary to repeat or alternate the two movements so as to produce a compound signal in each case. On this method an alphabet has been constructed, the invention being that of the late Professor Morse; it is now universally employed in Electro-Telegraphy. When two letters are composed of the same movements they are distinguished by the different order in which they are made: thus, one movement to the left followed by one to the right represents A, but one to the right followed by one to the left represents N.

107. The arrangement of signals representing all the letters of the alphabet is as follows, using R for right hand deflexion of the needle and L for left hand:—

LR	means	A	LL	means	I	RRLR	means	Q
RLLL	„	B	LRRR	„	J	LRL	„	R
RLRL	„	C	RLR	„	K	LLL	„	S
RLL	„	D	LRLL	„	L	R	„	T
L	„	E	RR	„	M	LLR	„	U
LLRL	„	F	RL	„	N	LLLR	„	V
RRL	„	G	RRR	„	O	LRR	„	W
LLLL	„	H	LRRL	„	P	RLLR	„	X
RLRR	means	Y	RRLL	means	Z			

The signal for E is also used to mean "understand" and the signal for T to represent "not understand," when the operator wishes to say he has or has not understood what preceded. There are many other combinations to express figures, diphthongs, and a variety of phrases employed in carrying on the work of a station.

108. It is difficult to realise what has really taken place during the time a single word has been sent through the circuit. Take one of three letters—the word "FOR"; there are ten different movements of the needle here, as will be seen by looking at the alphabet. Concurrently with each sharp, instantaneous movement

of the needle, a current of electricity has been *generated*, has compassed twice the distance between the stations, has given the impulse and ceased in a space of time equal to or less than that occupied by the tick of a watch, and this is repeated ten times to complete the word.

109. The instruments which depend for their usefulness on this principle are the "Needle," single and double, used exclusively on land lines for signalling—the "Mirror" or "Thomson's Reflector" employed for submarine telegraphy—and an instrument called the *Galvanometer*, or measurer of galvanic action, which is in truth but a form of the above-named, the difference being that it has a scale attached for measuring the strength of electric currents. The single needle instrument is, strictly speaking, a *Galvanoscope*, which means an instrument for detecting or watching a current, but not measuring its strength.

110. Of the action of the same property further explanation is needed. It will be easily understood that if a current of electricity passing in one direction on a conductor parallel to a magnetic needle deflects it, say, to the right, it would have deflected it to the left if it had passed parallel to the needle in the reverse way; and supposing two equal currents were flowing at the same time in exactly opposite directions along two parallel wires, both of which are on the same side of and equally distant from the needle, no deflexion can ensue because the currents neutralise each other's action. In fig. 7 the suspended magnetic needle *M*

Fig. 7.

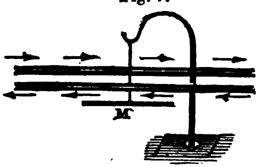
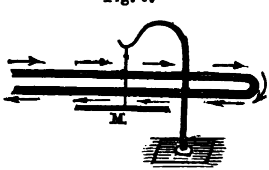


Fig. 8.



remains unmoved, while two equal and opposite currents are passing parallel to it.

Thus by the same rule *one* current flowing along a conductor arranged as in fig. 8 will produce no effect on the suspended needle *M*.

111. But there is another point—a current passing *above* the needle deflects it to the side opposite to that which it would take if this current passed below it in the same direction. Thus, if a current pass *over* the needle (fig. 9) and an exactly similar current pass *under* in the same direction, no effect is produced.

If, however, the conductor were arranged so that one part is above and the other below, a double

Fig. 9.

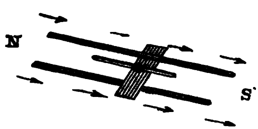
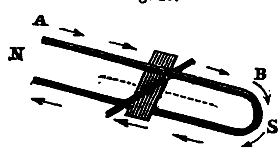


Fig. 10.

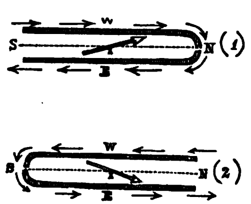


effect is secured. For, first the current flows from *A* to *B* over the needle (fig. 10), deflecting it (say) to the left or west, and then flowing under in the *reverse* direction, the needle is deflected still more to the left.

112. The rule that governs this influence of the current is unfailing. To have a clear idea of its action it will be well to conceive of the conducting wire which lies over or under the needle as having but one side with regard to the current. It will then be looking down on the needle from above and up to it from below, having its travelling face, as it were, always towards it. This is in accordance with the rule called "Ampère's rule," suggested by Ampère as useful towards remembering the direction which the needle will take under varying conditions of current. The rule supposes the figure of a man forming part of the circuit—in fact, we may say strung on the conducting wire, which is imagined to run right through his body from head to heels; this figure always faces the needle, thus it looks down on it from above and up to it from below. Then, "if a

current comes in by his feet and passes out by his head the *north* pole of the needle will always turn towards his *left* hand," he of course facing the needle. This is true under all variations; that is to say, if the direction of the current through the figure or the position of its face be reversed, the effect is also reversed. Suppose the figure looking down on the needle with its head pointing north, a current enters at his feet, that is from the south, and leaves by his head, and the north pole of the magnet turns to the *west*, or on his left hand. Suppose the figure now on his back, his head still to the north and looking up to the needle; a current coming in by his feet from south to north deflects the north pole of the magnet to the *east*, but this is on the figure's left hand, for he has turned completely over and his hands have exchanged positions.

Fig. 11.



(1) Current from S. to N. *over* deflects to W.
Current from N. to S. *under* deflects to W.
(2) Current from N. to S. *over* deflects to E.
Current from S. to N. *under* deflects to E.

113. It appears from the above that a current passing round from north to south *over* and back again from south to north *under* the needle acts with a double effect, and if it be made to pass over and under several times additional effect upon the needle is produced. So that, by continually passing fold over fold of conducting wire round the magnet we add to the power of the current. Care of course is taken that the wire is insulated throughout, by silk wound round it, otherwise the electricity would pass across the folds, and would not follow the course round.

114. From previous remarks it will be understood that to make the magnetic needle move from its position of rest the power of the current has to overcome

the "directive" action of the earth's magnetism (see par. 99) which is constantly at work upon it. If there were no restraining force of this kind an electric current would produce a much greater effect on the needle, and an arrangement, accordingly, can be made for neutralising the earth's "directive" action. Two magnetic needles are chosen as nearly as possible equal in magnetic qualities. Strictly speaking they ought to be exactly equal for the purpose required. They are then suspended by an unspun silk thread (to avoid twisting) passed through the centre of each, but their poles are placed in opposite ways, so that the north pole of one points in the direction of the south pole of the other. The result is that the earth's "directive" action on one needle is exactly counteracted by its power over the other, and such an arrangement, called an *Astatic* needle, points any way. An electric current acting on it has no opposing power to overcome, and the deflexions of this compound needle will be stronger than those of a single magnetic needle in a coil. If placed to the best advantage the force of the current passing through the coil acts on two needles instead of one, and the poles being reversed the action impels both in the same direction—being over the one from north to south and under the other from south to north.

115. A few words on pivoting the needle; it may be either *vertical* or *horizontal.* A needle pivoted *vertically*, or on a vertical pivot, as in a flat compass, would be a *horizontally* pivoted needle if the compass were made to stand on edge upright. In the first case the pivot has its point directed straight upright as if it grew out of the ground, and in the other case its point is directed horizontally, or as if it grew out of a wall.

116. The earth's action on a magnetic needle has been partly explained, but, besides making it point north and south, it tends to make it *dip* more or less on the earth's surface. When placed on a *vertical* pivot this action is not apparent, but if a magnetic

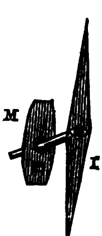
needle be placed on a *horizontal* pivot the north pole in the northern hemisphere *dips* downwards. This is called the "inclination." The *variation* explained above —viz., the fact that the magnetic needle does not point true north and south—is also called its "declination." A needle magnet pivoted horizontally must be weighted at one pole if required to stand upright.

CHAPTER VIII.

SINGLE NEEDLE INSTRUMENT DESCRIBED—COURSE OF CURRENT IN EITHER DIRECTION—SENDING KEY DESCRIBED—CIRCUITS TRACED THROUGH KEY, SENDING AND RECEIVING—CONNECTIONS AND COURSE IN CIRCUIT OF SEVERAL STATIONS—INTERIOR OF STATION—COMMUTATOR OR SWITCH.

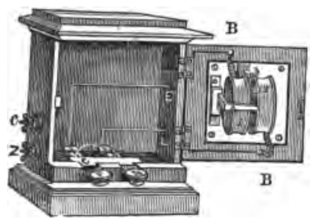
117. The single needle instrument consists of a magnet pivoted in the centre of a coil of very fine copper wire carefully insulated with silk, and passing many hundreds of times round, the two ends being soldered to two terminal buttons or screws to allow of any junction with a line or wire according to need. The magnet is concealed within the coil, and is pivoted with an index needle which appears on the dial, and which necessarily moves with the magnet (see diagram 12). The magnet *M* is marked with an *N* at its north pole.

Fig. 12.



The interior of the instrument with the door open is also shown in diagram 13, and on the outside of the door is the index needle, which is merely a piece of metal. There are also two little bone or ivory stops to prevent the needle from deflecting too far, and keep it more entirely under control. To the interior at the bottom is fitted the key (diagram 13) for sending the current through the instruments and the line and for changing its direction. *I I* is the coil, *B* and *B* the two terminals to which the ends of the coil are soldered. The black lines leading from these terminals are insulated connecting wires leading to the key, and to a point leading to the line. The screws *C* and *Z* are terminals for joining up the battery. The piece *A* is a support in which one pivot of the needle works.

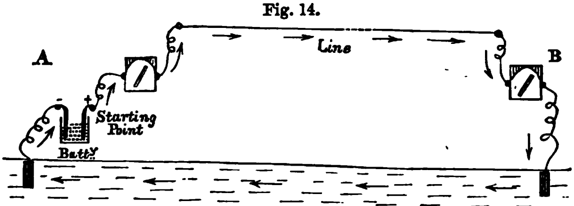
Fig. 13.



118. Before explaining the working of the key and the connections, it will be well to give a short outline of the arrangement in a needle circuit, and so afford a general idea of the course of the current when telegraphic business is going on.

We have a circuit from A to B, two stations, say 50 miles apart, and suppose messages to be from A to B. For simplicity's sake, the battery at B is omitted, as it is not really in *circuit* at a station *receiving*. We also omit the key connections at both stations, the explanations and diagrams being intended to show the principle at work, such detail being postponed.

Fig. 14.

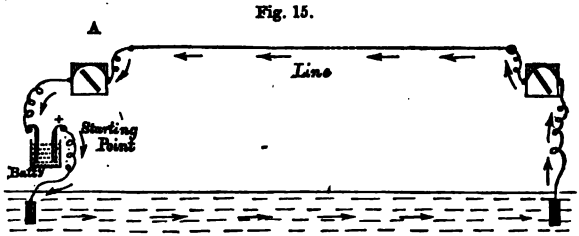


The passage of the current is here marked while it causes the needle at B to deflect (say) first to the right and then to the left. Its course is reversed in the latter case, and it will be seen presently that the connections enable this change to be instantaneously effected.

The relative proportions of the battery, instruments, &c., cannot be maintained in such limited space, and one cell is made to represent the battery, which may consist of any desired number.

In the first diagram (14) the current is made to leave the *positive* or + pole for the *line*, passing through the instrument at A; following the direction of the arrows it traverses the line and deflects the needle at B towards the right, thence by the earth plate and earth to the earth plate at A, and so round to the *negative* pole, completing the circuit. This is technically called sending a *positive* current; but, strictly speaking, it is a (positive) current sent "to line." In the next diagram (15) the course is reversed.

Fig. 15.

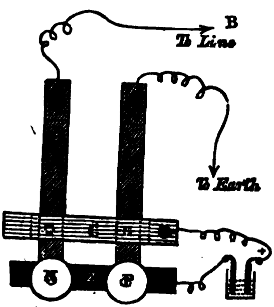


In this case the current still leaves the positive pole, but goes directly to earth, and, following the arrows, passes by the earth plate at B round the needle in the opposite direction to that in diagram 14 deflecting it to the left, thence by the line round the needle at A, and so to the negative pole, completing the circuit. This is technically called sending a negative current to line, but it is a (positive) current "to earth." The explanations in chap. III, par. 43, will have removed any difficulty in this respect. The operations thus outlined are those which take place in sending the letter N. (par. 107).

119. The arrangements by which a current is made to pass in either direction are shown in the following description of the key, a view of which is given as it would be if detached from the case which also holds the needle (or magnet) and coil. The material of which such apparatus is constructed is chosen with a view to prevent as far as possible any interference with the current; all keys and instruments should have their parts well insulated.

Z and *C* (fig. 16) are two bars, the former connected with the negative pole, and the latter with the positive pole of a battery. *L* and *E* are two springs which press against the bar *C*, and can be pressed down by the finger placed on *N* or *P*. These springs and bars must either all be made of metal so as to be conductors, or else at every point of contact between any two there must be conducting contact pieces with covered wires passing to the points where the battery and the earth and line are connected. For example, at the points where *N* and *P* make contact with the bar *Z*, unless *Z* were metallic (and conductive), a covered wire would be necessary, leading from a piece of metal fixed just where *N* would touch through a similar piece under *P*, and so on to the battery connection. At these contact points small platinum nipples are always fixed, not because this metal conducts better than copper or brass, for it does not, but to prevent oxydation or rust by the frequent passage of the current, which would

Fig. 16.



very soon accumulate on either of the two latter metals, but not nearly so soon on platinum.

120. By keeping in mind that a complete conductive circuit is necessary for the passage of a current of electricity, the state of affairs at any position of the key can be easily traced. When neither of the tappers is pressed down there is no circuit, for one pole—namely, the zinc, or negative—is cut off. When *E* is depressed—that is, by finger on *P* and touches *Z*—the circuit is from the positive (+) pole through *C* and *L* to line—generally through the coil of the instrument—and through the distant station to earth there, by earth and earth-plate at home through *E* to the negative pole (—) (see diagram 17). *S* in each diagram is the starting point of the current; the arrows denote the course.

Fig. 17.

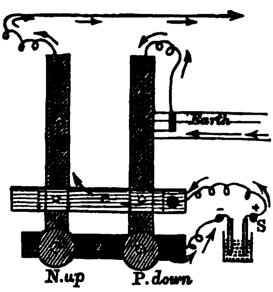
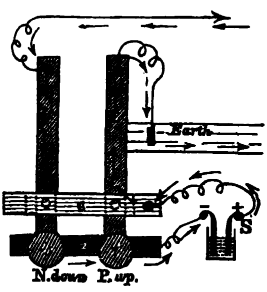


Fig. 18.



When *L* is depressed by finger placed on *N*, but *E* remains in its original position pressing up against *C*, the current will pass in the reverse direction—namely, from positive pole through *C*, but by *E* to earth, and by earth-plate at distant station through the line into home station through instrument, and by *L* to *Z* and negative pole (see diagram 18).

121. Many persons, describing this direction of the current, would speak of it as leaving the zinc or negative pole; thus the course of current in diagram 18

would by them be traced from *Z* through *L*, and they would call it a negative current. It is, however, simpler to hold to one current, always from the positive pole and merely reverse the direction.

122. The needle at distant station will turn right or left according to the direction of the current through its coils; and, of course, the arrangement of the key at the home station is made to correspond with the coil at the distant station, so that it is known at both places which way a particular current will move the needle. That is, the operator at the receiving station connects either end of the coil to the line or the earth connection, according to the way in which the connections are made to the key at the sending end.

123. The connections at any two stations in circuit together are thus pre-arranged, and are disturbed only when either of them is *sending*.

Let A and B be two stations in single needle circuit. A is telegraphing to B. The key is drawn separate from the needle instrument for convenience of explanation. In practice they are one. Fig. 16 will serve for reference.

The connections at B are in their normal or undisturbed position. It is impossible to show in the diagram more than just one passage of a current—that is to say, when a letter, or part of a letter, is being made. There are only two letters that can be formed by one signal each—namely, E and T. It is supposed here that the letter T is being sent. This is represented by one movement to the right in the needle instrument, and the circuit will be from line through L and C in the diagram, and through E to earth. This is, in fact, a portion of the course in diagram 14, but through the key only. At B it is seen that the current coming in by the coil passes through the key without having anything to do with the bar *Z* which is cut off.

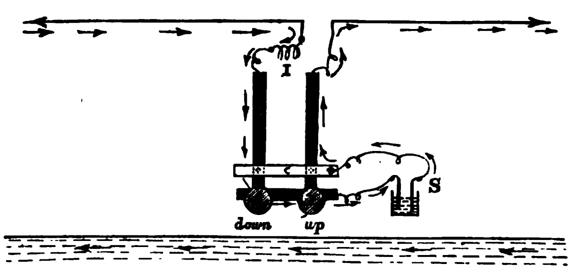
124. Since a telegraph line may comprise many stations we must show the course generally pursued, and how any two can communicate together, either with or

without the knowledge of the rest. However numerous the stations on a line may be, they must comprise a manageable circuit, and there must be two terminal stations, at each of which the line is kept constantly to earth. The stations between have, of course, earth connections also, but they are only used at any particular one for special reasons, as when communicating privately with another station. At all other times the connections must be so arranged as to permit the current to pass freely throughout the circuit.

125. It is necessary at this point to turn for a moment to the diagram of the key, and notice the spring *E*, which is there stated to be connected with the earth; this is the arrangement for a terminal station. At an intermediate station this spring would be connected with the line in the direction opposite to that which is joined to the further end of the needle coil at the same place. The current then coming in from above and entering the coil, say at the left hand, passes through the connections, and leaves the station by *E*, going on down the line to the right instead of going to earth.

126. Suppose at an *intermediate* station the operator be *sending*, the course of the current may be traced as in diagram 19. *I* is meant for the needle instrument. If *L* were joined through *I* to the other part of the line,

Fig. 19.



the signals would be reversed. Of course all stations are connected alike, that each may have the same signals.

Here a signal is being sent. If *N* be pressed down the current passes from the positive pole by *E* to the line on the right hand, and through all the stations in that direction to the terminal one, when it goes to earth, and by earth to the earth-plate at the other terminal station on the left, thence through the stations on that side till it comes home, entering through the coil and by *L* to the other pole. If P had been pressed down, the course would have been in the reverse direction.

127. The arrangements for a circuit "waiting for business" are now clear. Diagram 16 shows the position at a terminal, and diagram 19 at an intermediate station. Every station is prepared to notice a call from any other. Let a circuit consist of stations A, B, C, D, E, F, and A be desirous to communicate with D. The operator at A will first make the signal name for D, and as every station has a different word or symbol to distinguish it, each one knows whether he is called or not. The operator at D, seeing his station called, returns the *same* signal to show that he knows the fact, but he does not yet know by whom he was called. The operator at A, on receiving the answer, next gives the name of *his* station, and D again repeats the same to show he is aware who called him. The message is then sent in due course. The signals may be read at all the other stations, but, of course, the trouble would be useless.

128. If it be required to prevent any but the proper station from receiving the signals the arrangements must be altered. If A wishes to send a private message to D, the connections will be thus arranged.

The spring *E* at station D is connected through the coil to earth, and stations E and any below are thereby cut off. At stations B and C the current will be prevented passing through the needle coils by an arrangement available at need by which two points—one at which the coil begins, and another connected with the line terminal below—are connected by a kind of bridge of copper or brass, which offers so good a passage for the current that, *practically*, the whole of it passes over, avoiding the coil.

129. A little consideration of the foregoing will make it easy to understand how any number of stations in a circuit can communicate with each other, and the changes that can be made. For example, if, in the above circuit, D wishes to communicate with stations below, but not with those above, he will "put on earth" *against* C, the next above. This means that he will connect to the earth-plate the end of the line coming in from C, thus cutting off the upper section of the circuit, and will put the further end of the needle coil to earth also. But this is seldom required to be done.

130. The plan of *connections* within an intermediate station may be briefly stated. The line comes in from above and from below at two separate points; to each end is soldered the end of a "lead," consisting of a strand of two or more copper wires twisted and insulated by gutta-percha or india-rubber. These leads may be of any length, and, whether short or long, will be fastened at any desired point of contact by a *binding screw*.

The *earth* connections consist of large metal plates buried, if possible, in a damp spot, and sometimes with a bed of charcoal enclosing them. It is well to have more than one earth-plate in different spots, but of the same kind of metal. A water-pipe or the interior of a pump will serve for an "earth" in case of necessity.

"Leads" are taken from the plates and fastened to different terminals, so that any other leads, as, for instance, from the line, may be attached when required. This is "putting to earth."

The line can be put to earth in either direction, or by joining the two leads it can be separated altogether from the instrument. However complicated the arrangements at any station may appear, it is easy to make necessary changes by keeping the idea of a *circuit* in the mind, whether it be one of wire simply, or whether it comprise leads, pass through keys, instruments, &c.

131. An important auxiliary in a telegraph station, especially a central one, is a switch or commutator. It is employed for keeping in or out of circuit any portion of the arrangements when required. The accompanying diagrams (20 and 21) may serve to show how connections may be varied. A short bar or bridge is the simplest form of switch, and there are many ways of arranging such instruments. Whatever be the form of apparatus by which any portion of a circuit is cut off or introduced, the principle is that of a commutator;

Fig. 20.

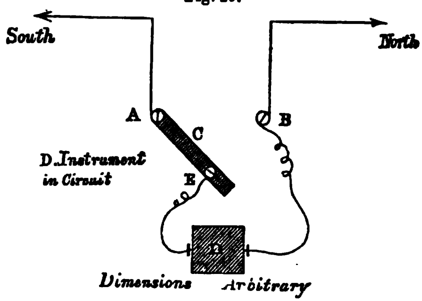
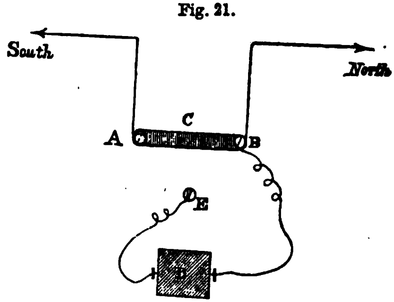


Fig. 21.



the needle-key in diagrams 16, &c., is a commutator.

"Peg" switches are very common; they are arranged so that the removal or insertion of a brass plug cuts or completes a circuit. The figures here given represent switches actually used in an office.

132. In working the key of the "needle" instrument the pressure must be firm, yet light. The easiest way is, to use the first and second fingers—one for each tapper. The index needle, and also the ivory stops, which limit its swing, will require gentle scraping now and then to prevent sticking. For general directions and detail for this and the "Morse" instrument, see *Culley's Handbook of Telegraphy*. There is a good School of Telegraphy in Conduit Street where all branches are taught.

CHAPTER IX.

EFFECT OF ELECTRIC CURRENT THROUGH A CONDUCTING COIL AND ROUND A BAR OF SOFT IRON—POLES DETERMINED BY DIRECTION OF CURRENT—RULES FOR DITTO —"MORSE RECORDER" DESCRIBED—ALPHABET FOR DITTO—KEY—"MORSE" CIRCUITS EXPLAINED.

133. The second condition mentioned in par. 103—namely, the power of the electric current to produce temporary magnetism in soft iron—is one of great importance in Electro-Telegraphy.

II. If a piece of insulated wire be coiled round a rod or bar of soft iron,* and a current of electricity be made to pass through the coil, the iron becomes magnetic during the time that the current lasts. When the current ceases, the magnetism disappears. This phenomenon is repeated as often as the current is started and cut off, and there is scarcely any limit to the rapidity of the changes.

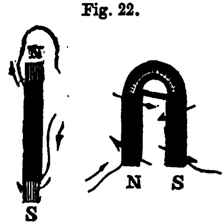
* This word relates to the distinction to be drawn between iron and steel. The former is called "soft," as opposed to tempered "hard" metal.

134. Since the iron remains magnetic whilst the current is in action round the coil, it must have its north and south poles, and, in short, have every property of a magnet. Therefore, if a piece of iron were placed near its poles it would be attracted and released from attraction as often as the current passed or ceased; and supposing such piece of iron were retained by a spring, or were so placed as to allow of its falling back, when released, by the action of gravity (its own weight) a series of movements, attraction and drawing back, would be effected. The piece of iron would be attracted when the current passed through the coil, and would be drawn back when it ceased.

135. A piece of iron so arranged is called the *armature*, and the instrument is called an electro-magnet.

136. The coil must be well *insulated* to prevent the passage of electricity from fold to fold, and also to prevent its passage to the iron *core*. If an electro-magnet be straight its poles are at each end; but to make it exert its full attraction on the armature, the magnet is bent into horse-shoe form, so that both poles may act upon it at once, and the attraction be doubled (diagram 22).

Fig. 22.



137. The question which end will be north and which south is decided by the direction in which the current passes through the coil. Just as the magnetic needle will be deflected east or west according to the direction of the current about it, so either pole of an electro-magnet can be made north or south by varying the direction of the current embracing it.

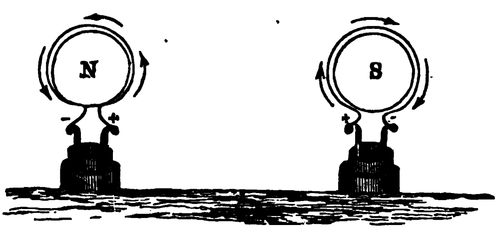
138. Intimately connected with this property of the electric current is the additional fact that it temporarily magnetises a "conducting wire arranged as a coil." Not merely does it magnetise the iron core of an electro-magnet, but if the core were removed, a

current passing in the hollow coil would make *it* a magnet.

139. Let us take a piece of *insulated* copper wire and wind it in a coil about a round ruler, not laying one coil on the other, but making a series of single turns, so that on withdrawing the ruler we have a skeleton cork-screw some inches long. If this be suspended, or balanced horizontally, so that it can turn freely, on passing a current of electricity through it, it becomes a temporary magnet and arranges itself in the magnetic meridian. The magnetic property endures only while the current lasts, but during that time the coil is a true magnet, having opposite poles, the direction of the current, as in other cases, determining which end is north and which south.*

140. A pretty little apparatus can be arranged by any one who desires to have proof of this fact. A piece of cork is hollowed and made to contain two small slips, one of copper and one of zinc, and a little diluted sulphuric acid (1 drop of acid to 8 of water) (see diagram).

Fig. 23.



A piece of silk-covered or gutta-percha-covered copper wire is made into a flat coil and the ends soldered to the two little plates. Then the whole is set afloat in a basin of water, and it will be seen that one side faces the north and the other the south.

* The figure thus arranged, with the ends of the coil brought back and prolonged so that it may be suspended, is called a solenoid.

141. Since the direction of the current determines which end is north or south, it is well to point out how to distinguish them; this explanation applies also to the electro-magnet, which is governed as to its poles by the same rules. A familiar one is that at the south pole the current passes *with* the hands of a watch, and at the north in the opposite direction. Again, if a piece of wire be wound round a round ruler, say, to the *right* hand *over*, when held endwise so as to look along its length, the coil will appear *right-handed*, thus  and if shifted end for end the coil will be reversed, thus  and be *left-handed*. Now A would represent a south pole and B a north pole, and by looking at the little floating magnets (diagram 23) we should find that at that side of the coil facing the south the current was passing in the direction followed by the hands of a watch. This is easily known, for the current *leaves* the copper plate (see chap. III.). As regards A and B, the current flowing in the direction of the arrowhead in either case in an electro-magnet so arranged would make a south or north pole according to its direction. The following note is given to assist the memory in retaining the rule which holds that "a *right over*-handed current makes a south pole, and a *left over*-handed current a north pole."

Winding right-handed from you, south pole next you.
Winding right-handed towards you, south pole next you.
Winding left-handed towards you, north pole next you.
Winding left-handed from you, north pole next you.

142. An electro-magnet is much more powerful (whilst its magnetism lasts) than an ordinary steel magnet of equal dimensions. The power depends on the strength of the current which *induces* the magnetism, and the number of turns of wire round the core.

143. The signalling instrument called the "Morse Recorder" is founded on the principle thus set forth. An electro-magnet is arranged with an *armature* held by a spring in such a way that it will move up or

down according as the current passes through the coil or is arrested.

144. The signals are not only made but are recorded as they pass by means of a style or pointer at the end of a lever on the other extremity of which the armature is fixed; when the latter is drawn down by the magnetism induced in the coil, the former is pushed up and makes a mark on a strip of paper arranged to pass close to it on rollers worked by clock-work (see diagram). In these two figures the merest outline is given to afford an idea of the arrangement in each case for recording the

Fig. 24.

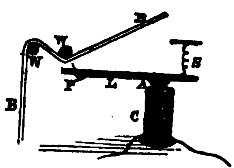
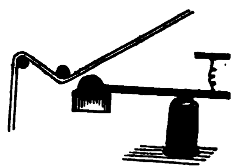


Fig. 25.



signals. *C* is the electro-magnet coil, *A* the armature, *L* the lever held up by the spring *S*, *B B* the paper strip moving round wheels *W W*, and *P* the style.

145. In another form of Recorder, in place of the style a small disc is attached to the lever, and is made to revolve in an ink-trough, and when the current passes and the armature is depressed, the inked disc rises and touches the paper strip, making a black mark, short or long according to the length of time the current is allowed to continue. On its ceasing, the disc descends again into its trough. This arrangement is shown in fig. 25. The distance is very small through which it rises and falls, and the lever is so arranged that the attractive power of the electro-magnet on the armature may be exerted to the best advantage.

146. In the needle instrument we saw that there were two distinct and opposite movements afforded as signals towards making up an alphabet; but in the Morse Recorder there is but one. It matters not which

way the current passes through the coils of the electro-magnet, because the poles simply attract the armature in either case.

147. In the "Needle" instrument the signals result from changing the *direction* of the current and index, but in the "Morse" they depend on the *duration* of the current. A shorter or longer period of keeping the armature attracted produces a dot or a dash on the paper—a momentary pressure of the disc or style making a dot, and a longer pressure making a line or dash. By combination of these longer or shorter movements, that is to say, of dots and dashes, the signals are made into an alphabet. The dot in the Morse alphabet corresponds to the left-hand movement of the needle alphabet, and the dash corresponds to the right-hand deflexion, and it may be said that the alphabets are really one.

148. Thus, one deflexion to the left followed by one to the right makes A in the needle code, and a dot followed by a dash makes A in the Morse code. The Morse alphabet is given here, and can be compared with the needle code on page 51.

A .—	F ..—.	K —.—	P .——.	U ..—
B —...	G ——.	L .—..	Q ——.—	V ...—
C —.—.	H	M ——	R .—.	W .——
D —..	I ..	N —.	S ...	X —..—
E .	J .———	O ———	T —	Y —.——
				Z ——..

There are numerous other symbols, such as "end of message," "begin another line," &c., &c., mostly made with not less than six dots and dashes, mixed. Different offices have different words for such purposes, but the letters of the alphabet are the same everywhere under this code.

149. Since the armature in this instrument is made of soft iron, it will be attracted equally by either pole of the electro-magnet; again, since the signals depend only on changes of *duration*, there is no necessity for any change of current. A current in either direction

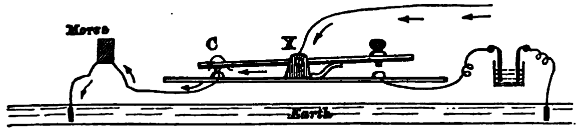
as may be preferred, and facilities for starting it and arresting it according to requirements, are all that is needed. For this purpose a key is used, the general arrangement of which may be gathered from diagram 26, which is sufficient to give an outline of the principle, though the form varies with different makers. The action of this key; which is called a single key, is easily seen. The lever turns on the axis, and is held up by a spring which tends to draw the end downwards. On the lever are two platinum nipples made to work against the two lower nipples, also of platinum (see fig. 26); these are arranged so that one pair only shall be in contact at a time. The lever is of brass or good conducting material, and the handle is of ebonite, a preparation of india-rubber possessing excellent insulating qualities. The lower nipples are connected with binding screws by wires, so that any *lead* can be joined on to them, and a continuous conducting path is thus prepared between the nipples and any line or point through which the current is to be transmitted.

150. The simplest kind of Morse Circuit comprises (besides the battery at either end) a single key for each station, the line wire and the recording instruments, with earth-plates completing the circuit, which for the present is supposed to consist of two terminal stations, A and B. The key at either station has no further communication with the recording instrument at the same station beyond serving as a means of connecting it with the key at the distant station by means of the line. The key at A causes the Morse at B to give signals, but does not act upon the Morse at its own station; on the contrary, as will be seen, it cuts it out from the circuit for the time, and the same with the arrangements at B. The key at each place is permanently in communication with the line, but temporarily with either the battery or the instrument.

This key is in one sense a commutator, but not the same kind as that in the needle instrument. The Morse key merely shifts the line from the instrument to the battery and back again.

151. The following diagram (26) shows the key in the receiving position, say at A. One pole of the battery is put to earth, and no current can pass from it, the circuit being interrupted. The current from B enters at X, traverses the lever through the two nipples in contact at C, and passes by the wire to the Morse, the path being marked by the arrows. Thence by earth to earth-plate

Station A. Fig. 26.

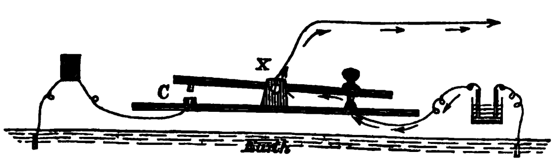


Battery at A not working, but cut off. Key in normal or receiving position.

at B, the earth-plate at A not interfering in the circuit.

152. The key at A remains in this position until the message from B is completed; but with regard to the next diagram (27), which represents the position of the key at B, while the current is passing, it must be remembered that after each contact there is an interval during which the key goes back to its position of rest. The contact is at most but momentary, and all that can be represented in diagram is the state of matters at the moment of its occurrence.

Station B. Fig. 27.



In the diagram, the key at B, or sending station, is pressed down at the handle end, and the current will pass in from the battery and go to line (following the arrows), this latter being, by the action of the key, cut off from the "Morse." The letters are the same in each diagram. Although the various *leads*, such as that to the line, to the battery, Morse, &c., are drawn in the figures, they would probably be out of sight in actual practice. The operator would do well always to know how the connections run, and keep the circuit in his mind.

153. The manner in which two stations are joined up in a "Morse" circuit is as follows:—A and B are two terminal stations supposed to form a circuit by themselves. It has been seen that when the operator at a station is *sending*, his "Morse" is cut out of circuit; the reason being that the coils of the electro-magnet would offer too much *resistance* (par. 16) to the current, and weaken its action. This being so, the operator has no means of knowing that his signals have any effect at the receiving station; though in circuit with each other, neither operator can make a signal that he can hear or see himself without some instrument connected up for the purpose. There is, therefore, a little instrument called a detector placed in circuit at each station; it is merely a small galvanometer, a small needle instrument without a key (see par. 117). The current must pass through each of these in either direction, and they act as informers to make known that all is right.

We suppose station A to be in the act of making a signal; the current passes through the "detector" and line, round the coil of B's instrument and through his "detector" and to earth—thence to earth-plate at A. If, when the key is pressed down at A, no movement be visible in the needle of the "detector" there, the operator would know that the circuit was broken somewhere. If the needle moves, he is certain his signals are noticeable at B. At every passage of the current the lever of B's electro-magnet is drawn down, and the disc touched against the moving paper strip, as represented in the figure.

CHAPTER X.

OFFICE OF THE "RELAY"—DESCRIPTION AND PRINCIPLE OF "RELAY"—CIRCUITS WITH "MORSE" AND "RELAY" TRACED—"TRANSLATION"—"OPEN" AND "CLOSED" CIRCUITS—DOUBLE ACTION RELAY—SIEMENS' POLARISED RELAY—"BRIGHT'S" BELLS DESCRIBED—CHEMICAL TELEGRAPHY—WHEATSTONE'S AUTOMATIC TRANSMITTER—POST OFFICE TELEGRAPH ARRANGEMENTS—HINTS TO ASSIST IN UNDERSTANDING THEM.

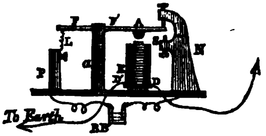
154. The arrangements for the "Morse" instrument, so far described, are suitable for short distances, but for long circuits additional aid is necessary, for which purpose an instrument called a Relay is employed. Its office is to carry on or retransmit the original signals by bringing into action a fresh battery at the place of reception; it may be used either to send this signal to a distant station along a further section of the line, or simply to send a fresh current from a local battery to the Morse at the same station. In any case it is employed to bring into action a fresh battery.

155. Suppose a circuit of any number of stations; A and B are the terminal stations and C is one half-way between them. The circuit is so long that the current from the battery at A will not produce good signals on the Morse at B, having been too much weakened by leakage on the way. At C a relay is provided, which, being moved by the current from A, brings into play a "local battery," from which a fresh current passes to B to work the Morse or another relay there.

When a relay is used at the station actually receiving the signals, it acts in the same way, but the "local" battery need only be strong enough to work the Morse at the same place. A relay and "local" battery are often needed, for a current from (say) A may not be strong enough to produce good signals on the recording instrument at (say) C, but has power to set a relay going at that station.

156. The principle of the apparatus may be seen in diagram 28, and there are many forms in which it could be constructed. An electro-magnet, *E*, is arranged to attract an armature, *A*, fixed to a lever, *F F'*, this lever being at one end, by *L* and *P*, in *conductive* communication with one pole of a "local" battery, *B B'*. The term *local* is used to distinguish this battery from the regular "line" battery. The "local" battery is like a change of horses, familiarly speaking—reserve forces to be applied as necessity compels.*

Fig. 28.



The lower part of the support *N* is of conducting material, but the upper part is insulating.

We will now show how a relay can be used to work a Morse at the same station. It is supposed that this *receiving* station is so far distant from the *sending* station that, without the relay, an enormous battery power would be required to work the Morse *direct;* but by employing a relay, a moderate battery power at the sending station suffices to set its lever in motion.

157. A current enters the coil at D, coming from the distant sending station; it traverses the coil and leaves it at D, going to earth (the end of the coil has been connected with the earth wire). Thence the circuit is completed, as far as concerns the battery producing this current, which travels back to the earth-plate at the sending station. The coil *E* becoming magnetic attracts the armature *A*, and the lever *F F'* touches *S*. It is seen that by this contact the "local" battery *B B'* is enabled to work—technically speaking, its circuit is *closed.* A Morse instrument is joined up as part of

* It is seen that the *local* battery *B B'* is "cut off" until the lever *F F'* touches *S*, when it is brought into play. Further, it has only a *wire* circuit here, and no instrument shown in circuit.

this circuit in practice.. The lever *F F′* is touching the screw *S*, and the local battery circuit is complete, which was not a circuit until the gap at *S* was closed (see diagram 28). *This* circuit will be traced from the positive pole through the *Morse* coil (not the relay) through *P* and the spring *L*, along *F F′* to *S*, and thence to the negative pole of the battery. One end of the "Morse" coil will be connected to one battery pole, and the other end to the relay at *P*. Our figure only shows the local battery joined up *without* the "Morse," which will be interposed in the circuit. A current thus traverses the Morse electro-magnet, and causes its armature to work. The advantage arises from the fact that the battery power at the sending station, though not strong enough to work the Morse recording instrument there, yet suffices to make the relay set in action the "local" battery, whose current has no line to traverse, but acts directly on the instrument close by.

158. As regards the connections for a long "Morse" circuit of two stations, with relays at each end, the course is as follows, say from A to B.

The current from A is from the positive pole of the "line" battery through line to B, through the key to the relay, and thence to earth, and home by earth to negative pole. The relay at B becoming magnetic draws down the lever and sets the "local" battery to work, which sends its current through the "Morse." Here is the general line circuit, and there is a local circuit inside each station, of which that at B only is working.

159. If the relay at a station be required to work a Morse or a relay at some other station further down the line, the connections of the "local" circuit are differently arranged. In the first place, the local battery current is not applied to an instrument in the same station, but must be made to travel down the line, but most likely a different and stronger "local" battery would be used. It comes to the same thing as if the

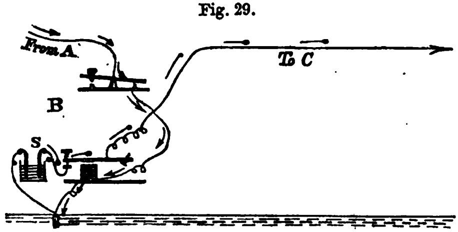
"Morse" at B station (par. 158) were 100 miles away. The "Morse" would be detached, and the "lead" which went from the key to one end of the "Morse" coil is now connected to the line. The pole of the "local" battery which had been joined to the other end of the "Morse" coil is put to earth; the current therefore set up in the local battery now passes to line and goes to earth through a relay or a "Morse" coil at the further station and returns by earth to earth-plate at B, and so on to the negative pole. The local circuit has become a line circuit completed between the two stations B and C (see fig. 29).

160. The above is the simplest form of relay, but before describing the other forms it is necessary to explain that the principle on which it acts is applied to a kind of operation called "translation." This is employed when it is necessary to work a Morse recorder at any number of stations on a line so that each may receive the same message. Here the Morse itself acts as a relay to work the local battery, at the same time printing its signals.

161. It must be mentioned in reference to the Morse instrument that the lever moved by the armature is limited in its play by two stops against which it strikes—against the upper one when the armature is released from the attraction of the electro-magnet, and against the lower one when drawn down by it. By comparing this part of the arrangement with the contact points in diagram 28, it will be easily seen how the Morse is made to act as a relay. The local battery connections would be arranged as has been seen, merely putting a Morse recorder in place of the relay. The result would be that this Morse would not only print the message which was passing, but would set a fresh battery in action to carry it on to next station (see diagram 29). The connecting lead might be taken from either of the points which limit the play of the Morse lever. But when the Morse is worked in this way for translating, the circuit can easily be arranged if the instrument

were not constructed with a view to this employment. By means of this operation the Queen's speech or any

Fig. 29.



The connections from the key and the *line* battery are omitted here. The *local* circuit follows blunt arrows. Morse is shown recording and setting fresh battery to work sending current to line.

important matter can be (and has often been) recorded at every important station from London to Aberdeen.

162. The line in the above descriptions has been worked on what is called "open circuit"; that is to say, the circuit was always open or incomplete until the current was started from the sending station. There is, however, another mode of working a line with relays, which in certain cases is preferred to the open circuit. In this, the *line* circuit is kept constantly *closed* when no communication is to be made, and only opened when a signal passes. It is called working on *closed circuit*, and is merely the reverse of the *open circuit*. The difference is that the "local" circuits are set in action by *breaking* the "line" circuit.

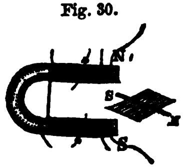
163. On this system the signals are made only by cutting off the line current, and arrested by keeping it going. The dots and dashes are therefore printed by stopping the current, and the spaces between arise from its passage. No line battery is needed at the intermediate station for close circuit; but if the line current, say, from A, be intended to work a Morse instrument direct at B, the close circuit method could not be employed without altering the recording arrangements.

One advantage of the system is, that a relay is more easily adjusted, and makes its contacts more readily by the lever being released than by its being attracted by the current.. When a current is continually passing, the lever is sure to be released on its ceasing, and the spring assists in the movement; but when a current is not flowing, but is to be started, its action is not so certain to have the proper effect on the lever. Familiarly speaking, "it is easier to let go than to lay hold."

164. The more complex forms of relay depend on the fact that the current in passing through the coils of an electro-magnet makes a north or a south pole according to its direction (see par. 137). This is of no importance when an armature of soft iron is used; but if a magnetised steel armature be applied in such a way that it can move to either side—as, for instance, if for an armature we had a pivoted magnet in the shape of a tongue—it would be attracted or repelled as the current through the coil made a north or a south pole.

165. A relay in this way can have a double action: a current in one direction through the electro-magnet attracts the magnetic tongue to one side, and in the other direction repels or attracts it to the other side.

Fig. 30.



An electro-magnet in the form of a horse-shoe (as in diagram 30) will act upon a magnet so pivoted according to the position of its (the magnet's) poles. By tracing an imaginary current in the figure, it will appear that entering at S a south pole is made there which will tend to attract the north pole of the magnet close to it. Following the coil, therefore, to the point where the current emerges at N, a north pole is made which will repel the north pole of the magnet. This repulsion assists the attraction of the south pole, and a double impulse is given to the magnet. A reverse current would deflect the magnet in the opposite way.

166. If, instead of one electro-magnet thus bent, we had two straight ones placed side by side and with one coil enclosing both, we could act upon a pivoted magnet at each end. This would be a double action relay, which we shall presently find employed to work another form of signalling instrument. The poles of the electro-magnet (the terminations of the cores) are made of little cubes of soft iron, between which the magnet works at each end. It is necessary that the magnetism induced by the current should commence and cease instantaneously, which would not be the case if the core or poles of the electro-magnet were of such material as steel; they would soon become permanently magnetic. There is always, however, some slight remains of magnetism in a coil after service, though, perhaps, not sufficient to give evidence of its presence. This is known as *residuary* magnetism. The magnets also which are influenced by the coil lose their magnetic power and require remagnetising.

167. There is another kind of relay, called a "polarised" relay, so made that when the tongue armature has once been deflected to make contact with any point, it will not return to its first position until a reverse current has been sent through the coils. The best-known form is that of Messrs. Siemens. A hard steel magnet is bent at right angles, and the north pole end consists of two branches terminating in little cubes, between which a tongue works. This tongue is made of soft iron, and becomes a south pole by its contact with the south pole of the permanent magnet. The coils of insulated wire are wound round the two north branches of the magnet in opposite directions, so that a current in one direction tends to make a north and south pole, while the reverse current would make a south and a north. The tongue being pivoted at its root, can oscillate between the cubes, these being so

adjusted that it shall not touch them, the required contacts being made by the end of the tongue.

168. In the adjustment of all electro-magnets care should be taken not to allow the armature actually to touch the poles of the core, otherwise they will be apt to stick there owing to *residual* magnetism; they should be adjusted at such a distance as experience shows to be best, the spring, where a spring is used, being proportioned in strength to the attractive power of the coil. There are screws fitted to them by which they can be tightened or relaxed.

There are other forms of relay, but the principle is in all cases the same, though varied in different forms.

169. The Morse signals may be read by the ear from the recording instrument, even if the paper be removed or the disc dispensed with, and also from the relay. There is an instrument called the "sounder," which is very popular in America. It is simply an electro-magnet with armature and lever, and the signals are read either from the sound of the lever striking against the stops which limit its play, or against a hollow box or drum arranged beneath it. Signals can be read faster by sound than by sight.

170. The next instrument for consideration is that known as "Bright's Bells," which may conveniently be introduced here, because the double action relay mentioned in par. 166 is generally used to work it. Though having gone somewhat out of favour in practice, it is worth noticing because the signals are easily learned, and by it a telegram can be taken down and despatched by one person more speedily than by any other instrument.

171. The signals are made by two little bells, each giving out a differently pitched sound. These correspond to the right and left movements of the "needle," and the dash and dot of the "Morse" instruments. The bells are little inverted shallow cups of bell-metal screwed on a horizontal pivot. The clappers are little

brass balls on short levers, these latter being fixed on horizontal hinges and suspended by a spring fixed near the former. The bells, which are set up one on each side of the instrument against an upright supporting board, face each other. On the centre of each lever a small armature is attached directly over the poles of an electro-magnet in the form of two upright coils connected together. The signal is given by the stroke of the clapper on the upper edge of the cup, the passage of a current through the coils drawing down the armature, which brings the lever with it. By means of a screw the spring can be adjusted to act on the lever in drawing it back with more or less force, so that a sharper or more deadened note is given out by the bell. The smallest sound, if it be distinct, affords a sufficient signal.

172. The bell coils are generally worked by a relay, because a somewhat powerful current is required to

Fig. 31.

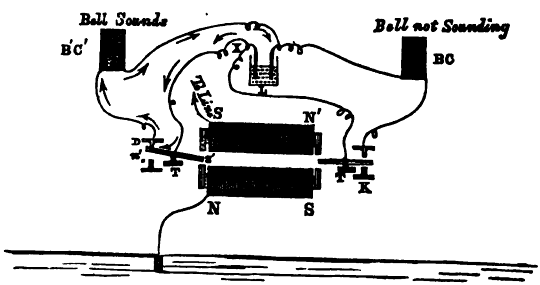


*Diagram 31 represents the form of relay employed.**

make them act freely through a long circuit. The connections are arranged as for a station *receiving* signals. The tongue pieces, *T* and *T'*, are fixed so as to turn EFFECTIVELY in one direction only; if they

* To avoid crowding the line current is not represented, but it comes in at *S'* and leaves at *N*, going to earth.

were to turn in the opposite way they would strike against stops to which no *lead* is brought.

173. According to the diagram, the line from the sending station is connected to *S′* and the earth to *N*. A current then coming in enters at *S′*, making a south pole, and, after traversing the coils, passes out at *N*, making it a north pole. By the attraction of *N* and the repulsion of *S′* on the south pole *s′* of the magnetic tongue, it is moved so that it makes contact at D. By this the local battery *L* is set in action, for the gap in the circuit between *n′* and D is closed; it sends a current through the coils of *B′ C′*, and the bell sounds. Meantime, looking at the other extremities of the relay coils, the current has made a north pole *N′* and a south pole *s*, which will really move the magnetic tongue *T*, so as to strike against the stop *K*.* There is nothing connected with this point, and so the local battery circuit on this side is still open; no current passes from it, and the bell, *B C*, does not sound. Thus, while the local circuit is closed (bell sounding) on one side, it is open at the other (no bell sounding). Though this occupies so long to describe, the current passes in different directions, and the bells sound alternately with the greatest rapidity. Thirty words a minute are quite feasible.

In practice the connections from the relay coils go to the key, which is rather complicated. It is arranged for an intermediate station, and of course there is also a line battery for *sending*. The signals when sent do not pass through the bell instrument at that station.

One objection to this instrument is that it requires constant care in adjusting the relay, and, in fact, every part of it. The key also is liable to get out of order.

The signalling on railways is chiefly carried on by instruments specially constructed. Generally speak-

* In the figure this tongue is drawn in its position of rest, though, in fact, it should be touching *K*. The object of this is to show the state of things when not at work.

ing, index needles are made to afford certain information according to the direction in which they turn. Bells are also used, but the principle in any case is included in the explanations already given.

174. The third condition mentioned in chap. VII., par. 103, cannot be considered at any length, chiefly because the principle is but rarely utilised in practical telegraphy.

A current of electricity, when made to act upon paper soaked in certain chemical solutions, decomposes the ingredients, and Prussian blue is deposited. A steel pointer is connected at the end of the line wire, and, a strip of the prepared paper passing constantly against it, is acted on only when the current is passing. A succession of short and long blue dashes is thus made just as the dots and dashes are made in the Morse. The difference is that here no electro-magnet is required, and chemical conditions perform the work which is done in the Morse printing by magnetic attraction acting as a mechanical force.

There are several varieties of this mode of communication.

175. The number of words per minute that can be sent on the "Morse" is limited to from twenty-five to thirty-five, and this speed is only safely attained by the best operators. *Automatic* sending instruments have, therefore, been invented, the best of which is that of the late Sir Charles Wheatstone, who has left behind him a number of most beautiful and useful inventions now extensively used in telegraphy.

176. "Wheatstone's Automatic Transmitter" enables as much as 500 words a minute to be easily and correctly transmitted.

177. The inventor thus describes it:—

"This invention consists of a new combination of mechanism for transmitting messages, previously prepared, through a telegraphic circuit, and causing them to be printed at a distant station.

"Long strips of paper are perforated by a machine, constructed for the purpose, with apertures grouped to represent the letters of the alphabet and other signs; a strip thus prepared is placed in an instrument associated with a rheomotor (or source of electric power), which, on being set in motion, moves it along, and causes it to act on two pins, in such manner that when one of them is elevated the current is transmitted to the telegraphic circuit in one direction; and when the other is elevated it is transmitted in the reverse direction: the elevations and depressions of these pins are governed by the apertures and intervening intervals. These currents, following each other indifferently in these two opposite directions, act upon a writing instrument at a distant station, in such manner as to produce corresponding marks on a slip of paper moved by appropriate mechanism."

178. Thus the message is first punched out as described, and the holes determine the proper succession of currents. On much the same principle the cards on a Jacquard loom determine the pattern woven. For the paper strip, after punching, is passed over an instrument in which two little "plungers" or "up-and-down moving" needles can only make contact with the line connections when the holes are directly over them. As this occurs they pass through momentarily and make contact. One plunger is connected with one pole of the battery, and the other with the other pole. Of course the speed can be very great as compared with contacts made by hand. Besides this, a message can be sent over and over again to several places. The several instruments are the "punching," the "transmitting," and the "receiving," which last prints Morse characters as the currents arrive.

In the postal telegraph office in London the "Morse" worked by hand and with "Wheatstone's Transmitter" is almost exclusively used. The needle is employed in smaller stations and suburban offices, and on the railways for conversing.

179. The large instrument room in the new buildings in St. Martin's-le-Grand is occupied by tables covered with the various sets of instruments, and some hundreds of telegraph operators, male and female, are engaged in sending, receiving, &c. The instruments are of the finest quality, and work for the most part in silence. The visitor is struck with the comparative quietude which prevails; there is no loud tapping, and there are no noisy contacts.

Each instrument has its circuit written over it, that is to say, the name of the town with which it communicates. They are all numbered and have leading wires coming up through the tables and connected to the battery-room and the lines. Corresponding numbers indicate the battery used in any circuit, and changes can be instantly made.

180. There are 30,000 battery cells in the building; the leading wires from these are brought up into an apartment boarded off from the operating room, and are fastened to terminals arranged in long rows on the face of the partition between the rooms. Each terminal projects on both faces of this boarding, so that a *lead* joined to it on one side is in conductive communication with any other *lead* connected to the same terminal on the other face. They are arranged in pairs, each pair representing a certain number of cells.

181. A long brass band traversing the length of the partition serves for earth connections, and is, of course, in communication with buried earth plates. It has terminals all along for putting to earth any instrument.

182. Previous explanations will have enabled the operation of "putting to earth" to be understood with reference to the arrangement now under notice. A few words, however, at this point may be useful to make the matter still clearer.

It will be borne in mind, in the first place, that but one wire at a time is employed for sending a message, and that an electric circuit uniting any two places is not a complete circuit of wire, but is, so to speak, one half metallic, and the other half is made up by the earth intervening between the terminations. It results from this that when an electric current is sent from a battery through a circuit, one pole of such battery must be to earth. But since it is necessary for practical purposes that alternate *positive* and *negative* currents should be sent without an instant's loss of time (in other words, that THE * current should be made to travel in either direction at will), a key is employed by means of which the shifting of the *leads* is obviated. It is therefore imperative that both poles of the battery should be permanently connected up to this key; and when the alternate contacts are made, by pressing the tappers of the "needle" key, or, as in the case of the "Wheatstone Transmitter," by the action of the "plungers" (see par. 178), each pole of the battery is put to earth as much as if the *leads* from either pole were in each case joined directly to the earth connections. The pole is, in fact, put to earth through the key.

183. There are some four hundred circuits out from this centre reaching all over Great Britain; but this department is not concerned with foreign telegraphy. This is in the hands of the various public companies, who, of course, control their own offices.

184. The Post Office Telegraph authorities are easy of approach by persons desirous of inspecting the instrument rooms. An introduction by some one known to the engineers and superior officers will suffice to procure a card of admission, specifying the date and hour convenient and the number of visitors on any one occasion. A competent official accompanies the party, and every courtesy is shown in explaining the arrangements. The ordinary visitor, uninformed in the technical details, will not, however, understand very much of what he sees. Supposing a reader of this little work to have the opportunity, he would probably think, at

* The point to be noticed here is the unity of the current (see par. 43).

first sight, that we had failed to give him much assistance. He must, in fact, carefully consider the preceding chapters, and, with the idea of the electrical circuit in his mind, watch the proceedings at some one working point; and, observing what particular instruments are being used, he will be able to understand what is going on. Say he places himself at a point where a message is being received by means of the Morse instrument. He will see the operator reading off from a strip of paper passing out from the "Recorder," which marks the dots and dashes as they arrive by the wire, such signals being formed by the action of the key at the station at the other end of the circuit. Or he may witness the same kind of operation reversed, namely, a message sent by the use of a similar key at this end.

The receiving "Morse" may be being worked by a Relay; this instrument will be placed close by—the form, as it appears, is that of a round box, glass-covered. The various connecting wires that are visible are not in any particular order as regards position. So also in watching the Duplex signalling. The various portions of the apparatus are all there, though not in the exact position as indicated in the diagram (fig. 36). As regards the Wheatstone Transmitter, the visitor may see some operators punching the holes constituting the intended signals on the strip of paper by means of one form of instrument (par. 178), and then passing it through the instrument, which transmits the alternate signals to the line. These operations are for *sending* messages. Again, for *receiving;* an operator is seen observing the printing of the received dots and dashes which were determined by the pre-arrangement of the last-mentioned portion of the "Wheatstone" apparatus effected at some distant station *sending* the message.

185. This great central office is the starting-point from which all telegrams are despatched to every point of the compass within the shores of Britain. It is also

the local station which receives generally those telegrams which are sent, for example, from towns south of London to others north. Further, all messages from one distant point of London to another, as from one postal district to another, are, as a rule, first sent to this centre and transmitted to their destination. The same course is followed with messages destined for the country.

186. A large number of messages is sent in bundles by means of the Pneumatic Telegraph. This arrangement is employed between the general office and such distant offices as Charing Cross, &c. The bundles are blown through a tube by atmospheric pressure, and much time and labour is saved. There are several of these tubes, which are found very useful.

CHAPTER XI.

COMPARISON OF LAND AND SUBMARINE TELEGRAPHS—DIFFERENCE EXPLAINED—MEANING OF "DIELECTRIC"—INSTANCED IN THE ATMOSPHERE AND THE INSULATING COVER OF TELEGRAPH CABLES—GRADUAL "CHARGE" IN CABLES—HOW A TELEGRAPH CABLE IS A "CONDENSER"—"INDUCTIVE EMBARRASSMENT" IN CABLES—POINTS CONSIDERED IN DESIGN OF A CABLE.

187. Probably no one would be disposed to doubt that there must be many points of distinction between a land line (overhead) and a submarine telegraph line. One passes through the air, the other under water. Certainly each must be constructed on a different plan. However, the distinction is really one of degree only—one principle governs both, but the conditions are different. The subject becomes complicated if followed up to any length, and but a brief attempt at explanation may be permitted here.

188. A telegraph line generally, of whatever kind, consists of an insulated conductor reaching from station to station. In a *land* line the conductor of iron wire is supported at repeated intervals on insulators of porcelain or stoneware, or some good non-conducting material to prevent the escape of the current to earth. A *submarine* line has a conductor of copper strand (twisted wires) which is insulated *throughout its length* by a covering of gutta-percha or india-rubber, for, as it must lie on the ground or in the water, it would otherwise be always in contact with the earth. The land wire is galvanised, and sometimes painted for protection against the weather. The submarine wire with insulating sheath, together forming what is termed the "core," is further protected by a serving of tanned yarn, and outside of all is a sheathing of wire also coated with hemp and tar. All these coverings outside the core are for defence against wear and tear, as the galvanising and paint for the land line.

189. Now from this comparison of the two arrangements it would appear at first sight that the gutta-percha or india-rubber in the submarine cable stands entirely in the same relation to the copper strand as the insulating supports to the iron wire of the land telegraph; and to a certain extent this is true. The object in both cases is the same, namely, to prevent the electric current from escaping to earth. But in a scientific point of view, and in actual fact, the gutta-percha or india-rubber discharges a function which something not yet taken into account about the land line also discharges; we allude now to the surrounding atmosphere. Though the land line is suspended or placed in the air, and the submarine cable is laid in the water, yet the atmosphere in the one case does not correspond to the water in the other. To lay the naked copper strand in the water would be, in fact, the same thing as to put the land wire constantly to earth. Therefore the latter is suspended in the atmosphere as completely as possible to insulate it from earth; and the former is

covered with gutta-percha for the same purpose. The principle at work in a scientific point of view is as follows :—

190. In every case of electric action there exist *three* conditions which must always be borne in mind. There must be two "opposing surfaces" on which the separated electricities can accumulate, such surfaces being separated by a medium through which they cannot recombine, or can only recombine more slowly than the *source* can generate them. One of these "opposing surfaces" is in most cases the earth; the other is found in any conducting surface that may be employed. The medium spoken of is properly called a *Dielectric*, that is, a non-conducting medium. These conditions can be traced in every case where electricity is set free, or produced. When the ancient experimenter rubbed the amber on the cloth, the electricity accumulated on both as "opposing" surfaces, and they were separated by the atmosphere, which could not let it recombine as fast as each act of friction produced it. In the submarine cable the *dielectric* is the gutta-percha or insulating cover, and in the case of the land line it is the surrounding atmosphere. The insulating supports of the latter, though non-conducting to a certain extent, are necessarily introduced because the atmosphere is not substantial, though a much better *dielectric*, and if supports for the wires were not required, there would be but this one *medium*, as there is one only in the submarine cable. Roughly speaking, the immense difference in degree as to the principle at work between the two kinds of line arises from the wide difference between the *dielectrics*. The atmosphere is (especially when dry) not only a very much better insulator than gutta-percha or any known substance, but it is also, as an envelope around the wire, almost infinitely greater in thickness than the insulating cover of the submarine copper strand. In quality and quantity both there is no comparision.

191. When electricity is produced in a body, or, in other words, when anything is electrified, it is said to be

charged, and whether the charge passes instantaneously off as in a current, or remains longer in action, there is still an accumulation on its surface. Whenever and wherever electricity is accumulated it exerts an influence on surrounding objects; this influence is called *Induction*, and produces a mutual attraction between the bodies.

192. The use of the word *Dielectric* in the sense of a medium for recombination of electricity implies the existence of two points or surfaces which it separates—as we said in the rule above, two *opposing* surfaces. In the land line these are the conducting wire and the earth (including all matters in contact with earth), and they are separated by the atmosphere as a *dielectric*. In the submarine cable the opposing surfaces are the copper strand, and the earth also (or the outer sheathing, which must always be in contact with earth), and these are separated by the gutta-percha or insulating cover as a *dielectric*.

193. The dielectric in the land line is so good, that is, it is so good a non-conductor, and also so comparatively extensive, that it resists the *induction* (which is a tendency to recombination) almost entirely, and practically no injurious effect is exerted by attraction on the current.

194. In a submarine cable the *dielectric* is inferior in non-conducting power, and is small as compared with the conducting wire. It resists the induction much less than the *dielectric* of the land line. The tendency to accumulation of the separated electricities on the two opposing surfaces is too great in proportion to the tendency to recombination afforded by the conductor; and *induction* to a comparatively great extent is the result—comparatively, that is, to that in the land line.

195. In the land line the wire conductor affords a means of recombination very great compared with the small *induction* or "side attraction" between the two surfaces, itself and the earth. Whereas in the submarine cable the proportions are much less favourable

to the recombination by the conductor as compared with the "side attraction."

196. The result is, that in a submarine cable the power of *induction* embarrasses the current, and it is, as it were, checking it and pulling it aside; thus signals are not received at the further end regularly as they are sent. The current is delayed continually through its course, and signals following each other too rapidly cause a "wave" current; if they are continued a "return" current is produced, which directly opposes the true one.

197. This effect may be illustrated by supposing a pipe to have water pumped into it at one end faster than it can escape at the other end; before long there will be a backward rush, a "return" current.

198. In the land line there is no apparent action of this kind; the electricity being very little retarded by induction, a recombination is effected instantaneously, so to speak, by means of the earth-plates, and, in fact, the conductor is discharged as quickly as charged. While the key connecting the battery is pressed down the current flows, and the conductor remains so far charged; and when the key is released, the charge is all gone, so that a fresh signal may follow at once. But in a submarine cable the release of the key is not accompanied by the entire discharge of the conductor; and if a fresh signal be made the new charge will encounter the lingering remnant, and confusion will ensue.

199. The fact is, that when contact is made, or a current sent into the line, it continues for some few seconds to be unequally distributed. For example, at the receiving end of a long cable such as one across the Atlantic a very small proportion of the permanent current that will afterwards flow equally throughout is to be found. Professor Jenkin says, "The current will gradually increase until, a second after the first contact was made" (contact with the key), "the current will have reached about half its final strength, and after about three seconds it will have

attained nearly its maximum strength; during the whole time the maximum current is flowing into the cable at the sending end." . . . "The current does not arrive all at once like a bullet, but grows gradually from a minimum to a maximum."

200. The investigation following the discovery of this difficulty in former days led the inquirers to see that a submarine cable presents all the features of a contrivance used to show the action of accumulated or *Static* electricity. This is the *Condenser*, the original type of which is known as the *Leyden Jar*, which was a glass jar with a coating of tinfoil pasted carefully inside and out extending to within a few inches of the mouth, but having no connection with each other. This last is generally closed by a wooden stopper, through which passes the stalk of a brass knob or ball; from this a chain reaches to the bottom, thus connecting the brass knob with the inner coating. When the brass ball is charged by bringing it into communication with an electrified body, as the prime conductor of an electrical machine, the inner surface is also charged with the same kind of electricity. At the same time the outer surface, in communication with the earth, is charged with the opposite kind of electricity, and, in fine, a quantity of electricity will accumulate in the jar to a certain limit depending on several conditions. If, however, the inner and outer coatings be brought into *conductive* communication together the jar is discharged. This is the earliest form of *condenser*, which, whatever be the construction, is an apparatus for accumulating electricity. There are always two conducting surfaces separated by a non-conducting medium, and electricity can be gathered in them to a certain limit in each case. In the Leyden jar, the inner and outer coatings of tinfoil are the two "opposing surfaces" separated by a *dielectric*, the glass, through which the electricities cannot recombine.

201. The electricity accumulated on either surface is of an opposite character—one positive, the other nega-

tive—and they remain until contact is made between the two, when the surfaces are discharged.

202. A submarine cable is, then, a kind of condenser. When in action it is charged or affected by an accumulation of electricity in a *static* form (par. 26). Thus after a cable has been charged, though it be only for fifteen seconds, several minutes are required to discharge it completely after removing the source. The *dielectric* (insulating cover) has been, as it were, *saturated*, and takes time to discharge the accumulation.

203. A land line at work is also charged, but the conditions are different, and no retarding inconvenience results. The quality as a non-conductor, and the vast extent of the atmosphere, which here is the *dielectric*, resist the *inductive* tendency, and the conductor is discharged as quickly as it was charged.

204. The *embarrassment* is naturally greater in proportion to the length of the cable, for the longer a cable of given section is, the larger must be the conducting surface, that is, surface for the accumulation of electricity; but the gutta-percha, though there is more of it, is still no thicker. Thus the conditions tending to produce *induction* are increased, while the resistance to it remains constant. If a mile of cable with a certain conductor had a dielectric, say, the seventh of an inch thick, an electric current will be protected, as regards embarrassment, by this thickness of insulator against a tendency in that direction estimated by the total amount of conducting surface. But in two miles of the same cable the surface is doubled, but the thickness of dielectric is unaltered.

205. The qualities of the wire conductor depend on the nature and thickness of the material; and the goodness of the *dielectric* depends on the *specific* power to resist *induction*—that is, on its insulating qualities, and on its thickness also. For as one insulating substance differs from another in its property as a non-conductor, the same thickness for different materials will not give the same resistance to induction.

206. The best submarine cable is that in which these conditions are so proportioned as to give the best signalling qualities. For example, if we have a certain length of cable with copper conductor and gutta-percha covering of a certain thickness, by substituting a copper conductor of greater thickness (but of equal purity) we get a better conducting surface, but also a larger surface for accumulation; and if at the same time we did not alter the condition of the gutta-percha covering, we have a greater *electro-static*, or accumulative, capacity, and no increase of *inductive resistance*. We have greater tendency to *inductive* (embarrassing) influence on the one hand, and no corresponding increase of *resistance to induction*. Enlarging the insulating cover of a certain length of cable without altering the conductor gives us *per se* greater proportional *inductive resistance*; and enlarging both without altering the length may produce no alteration.

207. The calculation of these points for a submarine cable is a very nice matter, and the highest mathematical abilities have been employed in forming exact rules for guidance. A hair's-breadth over or under the proper limit of thickness of material, that is, of the *core**—a difference in the purity of the copper used for conductor, or mistake in its section—a slight difference in the *specific inductive capacity* of the gutta-percha or india-rubber—these are some of the points which the telegraph engineers must take into consideration. The signalling qualities depend on these and other things; but after all the care bestowed on the construction of a submarine cable, special arrangements are necessary in practice to give sufficient clearness and speed to the signals themselves.

* The conductor with its *insulating* cover is called the "core."

CHAPTER XII.

SUBMARINE SIGNALLING—HOW A CABLE IS PLACED OR CONNECTED WITH THE OFFICE—THOMSON'S MIRROR INSTRUMENT — EMPLOYMENT OF CONDENSERS TO OBVIATE INDUCTIVE EMBARRASSMENT — THOMSON'S "RECORDER."

208. For good signalling it is necessary that the signals received should not run into each other, and that they should be severally distinct and intelligible.

209. To effect this in a submarine cable, contrivances are employed to insure that signals shall not enter the cable faster than they can leave it. These considerations are, in some measure, beyond our limits, yet a brief account of the means in use will be afforded.

210. The batteries employed are generally of some form of Daniell (chap. IV.), and the number of cells is according to the length of circuit, signalling instrument to be used, &c.

The submarine circuit may be said to resemble a land circuit in all respects if the conditions explained in chap. XI. are borne in mind.

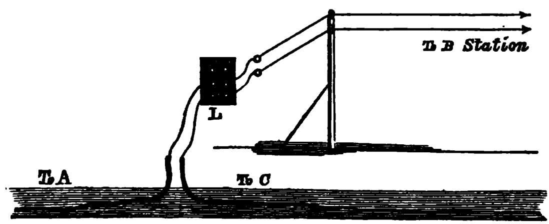
211. Earth-plates are not needed in cases where the conductor of the cable can be brought into contact with the outer sheathing. A cable is generally put to earth in this way when being tested, as it is so handy to take the earth-leading wire, or *lead*, and wrap the uncovered end round the body of the cable which comes up into the *cable-house*, the place where the cable itself ends.

212. When in course of laying, the cable ends when landed are generally buried in a trench running from the sea up to the cable-house. The extremity comes up inside this house or hut, and is brought into communication with a lightning protector, an arrangement to protect it from atmospheric electricity, by diverting the latter into the earth, and thence *leads* can

be attached as required. The cable-house is used only for testing the cable, and is generally at some considerable distance from the station, so that a land line is usually laid to unite them. When the connections are made, the end of the cable is practically in the station, and we speak of it as such, although the cable-house may be several miles off.

213. This is the arrangement at a terminal station, but at an intermediate station the cable is, practically, not *one*, but *two*. Suppose a station, B, say, on an island; that there is another, A, at some place 200 miles above, and another, C, at the same distance below. At the cable-house at the intermediate station the cable comes in from A, and the end being stripped of the outer sheathing for a yard or two, leaving the core, is brought up to the lightning protector *L* (diagram 32). The cable

Fig. 32.



also comes in from C, and that end is in like manner connected to the lightning guard, that is, to a separate part of it. Two land lines run from the *cable hut* to the station, and the ends soldered separately to *leads* at both places. The two cables are connected up by their leads to the land wires, and their ends become practically the ends of the two leads coming into the station. These can be connected to any desired terminal or contact point. The necessary connections are arranged in the station for signalling separately in either direction, or for allowing station A to signal through B to C, or *vice* *versâ* (see par. 130). One signalling or *line* battery is sufficient for, and can be connected up to, either cable as each is employed. This is done by means of a key to which the battery wires are joined, and the key is arranged to send currents in either direction, up or down the line. A good *earth* (see par. 130) is formed as near as may be to the office, and a strong *earth* wire runs along the wall for connecting up as required. All the *leads* are of stout copper wire and well insulated with gutta-percha or india-rubber.

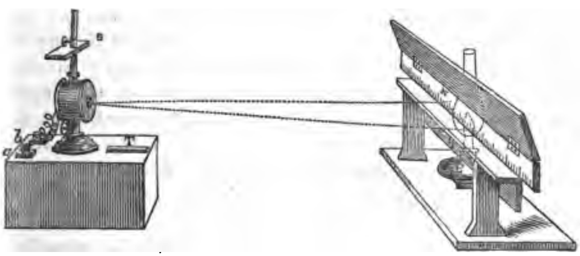
214. The instrument generally employed in submarine signalling is "Thomson's Reflector," or "The Mirror." A small piece of magnetised steel watch-spring, 3-8ths of an inch long, is fastened with shellac on the back of a little round concave mirror, and of about the size of a fourpenny or sixpenny piece. This is suspended by a piece of unspun silk thread in the centre of a coil of many hundred turns of fine copper wire insulated with silk and well protected between the turns with varnish. The two ends of the coil are soldered to terminal screws, as in the single needle instrument, so that any conducting wire can be joined up to it as required. The little mirror hangs in the middle of its coil, with the magnet lying horizontally. A paraffin lamp is made to throw its light through a slit on to the face of the little mirror, and opposite to this latter is fixed a board or scale on which the spot of light is reflected (see diagram 33). The mirror is so adjusted as to cause the spot of light to fall on the middle of the scale. Sometimes the lamp is shrouded in a hollow cylinder with a slit, the size of which can be adjusted by a slide, and then placed near the scale so as to throw its light on the mirror, instead of being underneath the latter, as in the figure. This last arrangement is usual in most signalling operations, the former method being employed when the mirror is used for other purposes.

215. When a current is passed through the coil the le magnet is deflected, as in the case of the single

needle; and since the magnet is fastened to the mirror, which is very light, both are deflected as forming one body, and the spot of light accordingly moves on the scale. The movement will be right or left, as the current passes in the one or other direction, and the signals are translated just as those for the right and left deflections of the single needle.

216. Since the mirror hangs freely it would vibrate when put in motion, and the spot of light would so shake about that there would be no certainty about the signals. A powerful steel magnet, *S* (diagram 33), in form of part of a circle, is placed above the coil, and acts so strongly on the tiny magnet in the coil that it tends

Fig. 33.



always to keep it at rest in one definite position. In some cases when a mirror is used on a short circuit a fine wire is fixed on the back of the little mirror, the end of which leads down into a jar or glass containing water, sometimes oil, and by means of a small *float* at the extremity of the wire every movement of the mirror is checked by the action of the float against the liquid. The object in any case is to make each little swing of the mirror to give a single decided and clear movement, followed by its return immediately to its position of rest. The spot of light should move right or left on the scale with a steady action, as far as can possibly be arranged.

217. The key is generally the same as we have described with the single needle (chap. VIII.) This form, in fact, was that which Sir W. Thomson used first for the "Mirror," but some prefer one kind of key and some another. The principle throughout must be nearly the same.

218. The principle of the "Mirror" invention has been of immense advantage in Electro-Telegraphy. Sir William Thomson, the inventor, has done more than almost any other person to facilitate improvement in nearly every department of the science. The great advantage of this instrument for signalling purposes is that it requires but a comparatively weak current to work it even through a very long circuit. When a pivoted needle is moved there is great resistance arising from friction at the pivot, and the magnet is enormously heavier and larger. In the "Mirror" there is no friction. It would require a very much stronger current to work a single needle or a Morse instrument or even a delicate relay on a long submarine circuit than to work the "Mirror"; and the weaker the current that must be used in a submarine cable the better both for speed and for the safety of the cable itself.

Notwithstanding every effort to keep the signals steady, the currents in a long cable are so irregular that the spot of light makes very unequal movements, and practice is required to interpret them correctly. The alphabet is, of course, that of the single needle.

219. Important as this instrument is for signalling purposes, it is no less necessary now-a-days when used as a galvanometer. The principle has been applied to a number of instruments for measuring the direction and strength of currents, and for determining and comparing the potential (par. 20) of accumulated electricity. The "Mirror" galvanometer supersedes all instruments with pivoted magnets for use on submarine lines, being infinitely more delicate and giving much clearer

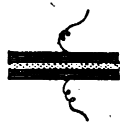
220. As regards its sensitiveness, it may be stated that signals have been transmitted across the Atlantic and perfectly well observed on the "Mirror" instrument by a current produced in a somewhat minute battery, namely, a thimble, with one zinc and one copper wire and a drop of sulphuric acid in water. Many Mirror operators find their eyesight affected by the habit of following the wandering deflexions of the spot of light. It is more difficult to learn to read than any other instrument, for there is no possibility of gaining any assistance from the ear, as in the needle, where there is always a slight sound due to its movement and striking against the stops. The ear helps the eye wonderfully in such cases, but the light wanders with a silent motion that is embarrassing.

221. It was remarked above that special devices are employed to insure the reception of clearly distinct signals, and several modes of arrangement have been tried. The difficulty arises from the retardation or *inductive* embarrassment which prevents signals from leaving the cable as they enter it. When a signal is made at the sending end, part of the current operates (say) on the "Mirror" at the receiving end, but part "lags behind," as it were, and comes on later, prolonging or confusing the deflexion first made. This first movement was sufficient for a signal, and one method of improvement consists in sending a short current of the opposite kind into the cable immediately after every signal, so that the *surplus*, the useless portion of the current just mentioned, is neutralised, and the signals are thus not confused. Keys are constructed in various ways for doing this, but the most ingenious and newest invention for this purpose is an automatic instrument which has just been patented by Sir W. Thomson and Professor Jenkin.

222. One way of obviating the difficulty is by using "Varley's Condensers." A condenser, as explained in par. 201, is an arrangement for accumulating a large quantity of electricity on a comparatively small surface.

It is easily seen that if one such arrangement can accumulate a quantity of electricity, a number put together will very much increase the effect. Condensers used in telegraphy are generally made of a number of sheets of tinfoil separated by mica or paraffin. Every alternate sheet of tinfoil is connected by a strip of the same material to the next but one, the first to the third, the second to the fourth, and so on. The object is to get as large a surface for accumulation as possible. In this way, although a condenser consists of a number of sheets or coatings it may be represented as if there were but two, with the insulating medium between them,* thus (diagram 34). Each of the *armatures*, as they are called, has its *pole* or termination, to which connections are made as required.

Fig. 34.



In using it one pole must be put to earth, or very little electricity can be accumulated on the other armature, and as these are separated by an *insulating* substance, that one which is *charged* directly from the *Source* acts *inductively* or by attraction on the other, so that this latter is not charged directly but is acted on by *induction.*

223. In using the condenser for submarine signalling the arrangements are as in the diagram (35).

C and *C′* are large condensers, one at each end of the circuit A to B. When the key at A is depressed the armature *m* is charged *directly*, and by induction acts on *m′*, this being connected through the cable to armature *n′* at B station, the latter is *inductively* charged and re-acts on *n*, which is connected with the mirror *R*. A short current passes through *R* and causes a deflexion. This current begins gradually, is very small, and would gradually die out, but the key at A station, immediately after making the signal by contact with *L′*,

* Condensers are generally made in the form of a round box, that is, the sheets are enclosed in a circular brass box with ebonite [illegible] bottom.

is raised, and the end *K* puts the armature *M* to earth through the earth wire by contact with *L*. A deflexion in the opposite direction is made by bringing the other battery pole into play instead of that

Fig. 35.

supposed in the diagram. This would be done by employing the ordinary double-action key mentioned above. It is omitted here for convenience of showing how a signal is made.

224. Sir William Thomson's "Syphon Recorder" must not be omitted in mentioning submarine signalling instruments. By this beautiful invention each current as it arrives causes a fine glass tube to be deflected, from the end of which a succession of drops of ink is spirted on to a strip of moving paper. This produces a wavy line on the paper, in which deflections to the right or left of the centre position have the same meaning as the deflections of the single needle or mirror. Its great advantage lies in the fact that enables very feeble currents to be recorded. (See Jenkin's "Text Book of Electricity.")

CHAPTER XIII.

DUPLEX SIGNALLING—PRINCIPLE EXPLAINED—CIRCUIT TRACED.

225. One of the most remarkable operations in Electro-Telegraphy is that of signalling at the same moment from both ends of a circuit on a single wire. This is called "Duplex" telegraphy. An operator at station A can telegraph to station B at the same time that B is telegraphing to A. There have been several arrangements for this feat, but that which is now to be described is of comparatively recent date. Twenty years ago *Duplex* telegraphy was thoroughly tried and pronounced impracticable, at least it could not with the means then employed be usefully applied to signalling purposes.

226. The principle in any case depends on the fact that the difference between two unequal and opposite currents produces the same effect as a single one of less power than either. If two currents of equal strength pass through a conductor in opposite directions they neutralise each other, and no effect would be produced on an instrument, such as a relay, arranged so as to be subject to the influences of the current. But if one be more powerful than the other, an effect will be produced equivalent to that due to the difference in their strength.

227. The conditions under which the operation is carried out are these. In the first place, the signalling instrument at each station is worked by a Relay. The principle of the Relay has been explained in chap. X. and in showing the Duplex operation we need not go beyond the working of this appliance.

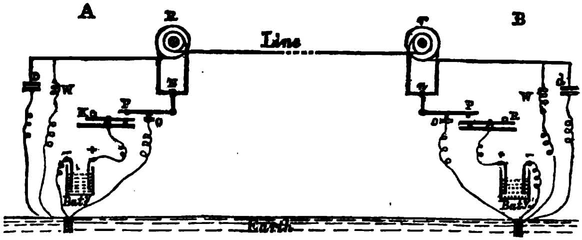
The operator at either end when signalling *alone* cannot make his own Relay work. When he is working *separately* the current which he produces certainly passes through the Relay at his station—say A—but its construction is such that the effect through one-half is neutralised by the other half, and the current passes to him and acts only on the Relay at the other station, B. But if the other station, B, begins working at the same time, the current which B produces acts on the Relay at A, and works it by neutralising that part of A's current which had prevented the other half from acting, and B makes the required signal at A really by means of half of A's current. At the same time the current from A which had made the signal at B neutralises the half of B's current which had prevented his Relay from working (when operating separately), and allows the remainder to act, just as was the case at A. So that when A (or B) is working separately his current works the other's Relay *directly*, but cannot act on his own; and when both work together, A (or B) removes the impediment from the other's Relay, and does not act *directly* on it as before, although the effect is just the same, and B does the same for A. If either station, say A, begins first and before one signal is complete at B, B begins to work, then the signal at B is not completed by the *direct* agency which began it but by B's own current, which can only act on its own Relay when A is at work.

228. The operator at either station controls the length of the signal he wishes to make at the distant station just as if he *alone* were signalling; because it is only whilst he holds down his key that any effect is produced at the other end, and it comes to the same thing whether the signal is caused directly by the battery at his station or *indirectly* by that current's influence on the current arising at the other station.

229. The arrangements are as follows, and are, of course, exactly the same at each station (see diagram):—A battery is connected by a simple contact key, *K*, to a point, *N*. The key is seen in the figure to

be in its proper position when not working; by press-

Fig. 36.



ing it down at the handle end it connects the battery to the point *P*. And it must be noted that the battery is not set to work at the instant of this contact, nor until the moveable piece *P* is lifted from the point *O*. The object of this arrangement is, that *N* may be in communication with the earth at certain stages; this will be understood when a careful observation of the figure has made the explanation clearly intelligible. From the point *N* two connecting wires lead to a Relay, *R*, consisting of a soft iron core having round it two equal coils wound in opposite directions. The further end of one coil is connected to the line, and the further end of the other coil is connected to a resistance coil, *W* (par. 24). This resistance is adjusted so as to equal that of the line and connecting wires going to earth at the other station. Both stations have exactly similar arrangements. The *condenser*, *D*, is introduced to give additional security that the currents shall not be retarded by mutual action. The condenser and the resistance coil amount to an artificial line equal as regards electrical qualities with the real line. The same letters are used for both stations—capitals for A and small letters for B.

230. Let a current be passed from the battery at A when B is not working. It goes to *N*, where it divides, and half goes one way through the inner coil, and half flows the other way through the outer coil. Now a

current passing through either coil separately would magnetise the soft iron core, and the *armature* (par. 156) would be drawn down; but since the circuits of which each coil is a part are equal in resistance, the equal currents (or half currents) oppose each other and the core is not magnetised. Thus no effect is produced at A when working alone. Of course it is the same thing with B if that station were working alone. But let us follow the current (or half current) after leaving the *inner* coil of the Relay. It goes to line, and through the inner coil of B's relay, and since there is no opposing current through the outer coil of this relay, the core is magnetised and a signal made.

231. But if B were sending at the same time, his battery current divides at N (as A's did at *N*), but the half which goes through the inner coil and so to line meets that of A coming from the opposite direction. They are neutralised. This leaves the other half of B's current free to act alone on the core of his relay, and accordingly a signal is produced there. It is really A's signal which is made, but it is wrought, as explained, by part of B's current. In the same way a signal is made at A by corresponding action. Under these circumstances, that is, when A and B are signalling at the same moment, A compels B's current to make or finish the signal he wishes to send, and B compels A to do likewise. Each controls and limits the length of signal produced, whether for dash or dot (chap. IX.).

232. The accuracy of the results depends upon the arrangement of the resistances. The practical application of Duplex telegraphy as here described is the work of Mr. Stearn, an American. Mr. W. H. Preece also successfully introduced a mode of working on somewhat different principles. Improvements have been made in America, by which two separate instruments are worked at each station at the same time by one wire only. This is effected by the use of relays which are affected by different strengths of currents.

CHAPTER XIV.

MEASUREMENT OF CURRENTS — GALVANOMETERS, THEIR USE AND PRINCIPLE — VARIOUS DESCRIPTIONS — THE "DIFFERENTIAL" GALVANOMETER—ANALOGY TO A PAIR OF SCALES—"MIRROR" GALVANOMETER—ADVANTAGES POINTED OUT—RESISTANCE OF CONDUCTORS—TESTING FOR QUALITIES AND FAULTS.

233. We have not space for a full consideration of the measurement of electric currents, or the principle on which telegraph lines are tested for the observation and correction of their qualities; but the subject is of great importance in telegraphy, and it must be briefly considered. The instrument employed for this purpose is the Galvanometer. It has been explained that the strength of a current is measured by the amount of deflexion of a pivoted or suspended magnetic needle from its position of rest when the current is passing round it through a multiplying coil. There are varieties of this instrument, but a knowledge of trigonometry is necessary to understand the subject properly, which is also beyond the scope of these pages.

234. It will be remembered that the magnetic needle when at rest lies in the magnetic meridian, say, north and south, and according to the direction of a current through the coil round it, its point turns east or west. Suppose a magnetic needle pivoted in the centre of a coil of insulated wire and having an index needle to move with it, the latter appearing on a dial as in a watch, pointing to six o'clock. This would represent the ordinary "Detector" employed for detecting and roughly estimating a current where no particular accuracy is required. The circle is divided into 360 equal arcs or portions; there are therefore 90 in each quarter. The point of the needle when at rest is at zero (0), which occupies the place corresponding to XII in a clock, and

for reasons given in chap. VII., the needle is weighted to keep in this position. When a current passes round the coil the needle is deflected, say, to some point between 0 and 90°, and there it will remain until the current ceases. If this point be half-way between 0 and 90° the needle will be said to be deflected 45 degrees. Each arc of the circle *subtends*, or is opposite to an angle of 1 degree. The *angle* therefore measured here by the needle is one of 45 degrees, and is in fact the angle made by two lines drawn from the centre to 0 and 45°. We should say of the current in question that it produced a deflection of 45 degrees.

235. But the strongest current that could be produced cannot keep the needle deflected beyond the 90°. In the same way a current in the other direction could not deflect it beyond the point 90° on the other side. It follows from this that the amount of deflection of the needle is not the direct measure of the strength of a current, since a strong current might deflect it to nearly 90°, but one twice as strong could do little or no more. Therefore, under ordinary circumstances, only moderate currents could be compared on the instrument without the help of other appliances. It is not the earth's restraining power (chap. VII.) that prevents the magnet from deflecting over 90°, for the same rule holds with an *astatic* needle, which, as explained in par. 114, is not under the earth's influence. The reason, of course, is that the power of the current tending to deflect the needle to the *right* hand, or east of north, would be tending to turn it towards the other side, or west, if it impelled it beyond due east. It can only impel it to a distance something short of due right or left.

236. If one current cause a deflection of 20°, and another current give 40°, the first is not, as might be thought, half as powerful as the second. The explanation of this fact helps to account for that previously stated. The influence of the current over the needle is greater in proportion as it is more nearly parallel to it,

and when the needle is at right angles to the current no effect is produced. Now the first current deflects the needle to 20°, but while at starting it flowed parallel to it, and so acted to the best advantage, it must produce less effect in proportion as the needle advances than it did at first. It is plain that it caused the deflection to the first 10° more easily than to the next 10°. The second current drives the needle to 40°, it must therefore be more than twice as strong as the first, as the further the needle advanced the more it passed beyond the best position for feeling the influence of the impelling power. It results, therefore, that, as measured on the ordinary "Detector," the strength of an electric current is not measured by the angle of deflection of the needle. But to go into this subject would carry us much too far. It is enough to say that a galvanometer of this sort is graduated on the principle set forth, and the degrees marked on the dial are *not equal degrees of a circle*, but degrees of *intensity* as they are sometimes called. This means that they represent the relative strength of currents deflecting the needle. A current giving 40 of these degrees of intensity may be considered to be just twice as strong as one giving 20.

237. Galvanometers with pivoted needles are used almost exclusively on land lines, and even when made *astatic*, are not sufficiently sensitive for submarine cable testing.

238. In a more delicate form of galvanometer than the "Detector" the needle is suspended by an unspun silk thread (a fibre pulled out of a silk ribbon will do); a second magnetic needle joined by a copper wire is within the coil, its poles reversed, the whole being an *astatic* arrangement. The instrument is inclosed in a glass case. This is a very sensitive instrument. A penknife brought within a yard of it will deflect the needle sensibly.

This form of galvanometer may be purchased for £4 4*s*.

239. A "Differential" Galvanometer consists of a magnetic needle surrounded by two separate coils of

equal length and material carefully insulated from each other and wound in opposite direction. In using it one circuit acts against the other. If a current of equal strength were passing through each, there would be no deflection of the needle, because the influence in both directions is equal. If one current were stronger than the other, the needle would be deflected by the stronger (chap. VII.).

240. The needle of a Differential Galvanometer occupies an analogous position, as regards its action, to that of the upright pointer or spike in the middle of the suspending bar of a pair of scales. When the scales are held up empty the pointer stands perpendicular, as an equal weight is on both sides. This would also be the case if an ounce or a pound weight were put into each. But if a weight were placed in one scale-pan and no weight, or a lighter one, in the other, of course the pointer would *slant*, or make an angle with the perpendicular line which marked its position when upright. This angle would, in fact, be a measure of the degree in which one scale-pan and contents outweighed the other.

Suppose a pair of scales were arranged with a dial fixed behind the pointer,* which would sweep over the dial's face as it moved either way. Let this dial be graduated or marked near its edge with figures on each half of its front face from 0 to 100, the spaces between the figures being exactly equal. The pointer would mark 0 when the scale-pans were empty. Now, suppose an ounce weight to be placed in one scale and the pointer to be thereby *deflected* to the figure 10; next, let a second ounce weight be put into the other scale, and the pointer would travel back to 0, both sides are again equal. Let a third ounce weight be placed in the last-mentioned scale, and the pointer would be deflected to 10 on *that* side, showing that the *excess* of weight there was one ounce, or equivalent to 10 of

* Scales with a hand pivoted on a dial are used in many kinds of shops, and will here occur to the reader's mind.

the divisions or degrees. The actual weight is *two* ounces on the heavier side, but one is balanced by an ounce on the other side. If straight lines were drawn from the centre of the dial to each figure, the angle would be indicated (representing the deflection due to one ounce) in a circle containing 200 equal arcs. This analogy roughly explains the principle of the Differential Galvanometer.

241. The galvanometers used for testing cables are all on the principle of Thomson's Mirror. A gálvanometer of the most sensitive form has many thousand turns of fine wire in its coils, and the system is generally astatic, one mirror being below the other, but concealed. The upper mirror reflects the movement on to the scale (see *Mirror*, chap. XII.). There is a steel magnet placed underneath the lower coil or above the upper one, and this can be moved in either direction as required to adjust the mirror, that it may hang at such an angle as shall allow the spot of light to fall on any required part of the scale. A hair's-breadth change in the position of the magnet is not too little to influence the tiny magnet on the mirror. This steel magnet keeps the other steady and prevents vibration. The deflections in this instrument are true measures of the strength of the current. The divisions marked on the scale must represent very small angles, and if it were desired to measure the whole 90°, or quadrant of a circle on each side of zero, the scale would necessarily be large enough to stretch across a wide space in comparison with the small sweep in the circle on a "Detector." For these reasons very minute differences can be measured by the mirror instrument.

242. There are other forms of galvanometer which it is not necessary to notice here. This outline will suffice for the instruments *by* which to measure electrical currents—our scales, in fact; it is necessary also to have something to measure *against*, corresponding to the weights used in the scales. This may be made plainer by comparison.

243. We have spoken of the *resistance* of bodies to the passage of electricity as a current, and explained that those which are called non-conductors are said to have most resistance. But it is not enough to say that one body has more resistance than another; there must be some means of measuring it. Just as in ordinary affairs it would not be enough to say that one loaf was heavier than another, nor even to say that it weighed twice as much, unless there were some *standard* to which to refer them. This standard for the loaf is the pound or the ounce; and so in regard to measures of length, the standard is the inch or the yard. The Galvanometer, then, represents our scales, and we require something to represent the weights. The standard now almost exclusively employed for electrical resistance is called the "*Ohm*," from the late Professor Ohm, and to it all varieties of *conductors* are referred.

244. The standard of length is a certain metal rod authorised by Government to be called a *yard*, and other units of length are multiples and submultiples of it.

245. As a rule, persons seldom stop to consider how such an indispensable standard as a yard is obtained; all they care to know is that a yard is a measure of three feet, and so forth. It must be derived originally from some unalterable and ever available phenomenon. We may as well mention the rule here.

It is an established fact that a pendulum which beats seconds, or whose swing occupies one second when in a *vacuum*—that is, so placed as to be entirely free from atmospheric influence—and at the level of the sea at Greenwich, measures 39·139 inches (in other words, $39\frac{1}{7}$ inch nearly). This length would be unsuitable for obtaining submultiples (proportional smaller quantities), for it is not exactly divisible by any whole number. It was therefore arranged that a length known to measure 36 inches, or rather a proportion of such pendulum measuring 36 parts out of $39\frac{1}{7}$ (roughly), should be the standard yard. If it were necessary to find this standard now, the course followed would be to get a pendulum which would beat seconds under the above conditions, and then dividing it into 39·139 equal parts, mark off 36 such portions, and this would be the standard yard.

246. The *metre*, or French standard of length, is a certain submultiple of the diameter of the earth. The standard of time, or the second, is derived from observation of the earth's revolution. The standard measures, such as the yard measure or the pound weight, may be lost or destroyed, and the only security for always obtaining reliable standards is the permanence of the great natural laws of our globe.

247. The *Ohm* is obtained by observing what effect is produced by a current of electricity on a certain conductor in a certain time. As a certain metal rod represents the yard, so a wire of a certain resistance represents the *Ohm*. The *Ohm* is a small coil of German silver wire, representing the resistance overcome by a current in a certain time. German silver is used because its resistance is nearly eleven times greater than that of copper, so that a much shorter length need be used, and also because its resistance varies much less under changes of temperature than is the case with other suitable conductors. For all metal conductors present greater resistance as they get hotter.

The *Ohm* being the standard, any multiple or submultiple of it can be made, and resistance coils are, in fact, constructed in sets, as weights are.

248. The construction of a set of resistance coils may be thus explained: an oblong box is constructed of non-conducting material, that the partitions may be completely insulated from each other. The top is covered with ebonite, along the surface of which brass bands are arranged in a line, with small apertures between their ends, and brass plugs with ebonite tops are nicely fitted to the spaces, so that when all these are filled there is an unbroken line of good conducting material all through. Binding screws are fixed

in the ends of the brass bands. In each of the partitions a resistance coil is placed, the two ends of *each* coil fixed, one to the end of one section of the brass band, and the other to the nearest end of the next section, so that every coil joins one section to the next. These coils may be of any required resistance, increasing consecutively, as, for example, 10 ohms, 100, 500, or, 1, 2, 5, 10, 20, and so on. Suppose the box placed in circuit by attaching *leads* to the binding screws, so that the current should pass through it from one end to the other; if all the plugs were in their places, the current would practically meet with no resistance. But if any one of the plugs be removed, then the coil in that section comes into circuit directly in the path of the current, and just so much resistance is introduced into the circuit. Thus by withdrawing any or all of the plugs we can introduce less or more resistance

249. These coils are indispensable, but they are very expensive. They are generally arranged so that a box, or set, will measure 10,000 ohms, or any less quantity. Any number from 1 up to 10,000 can be introduced, and if any particular number is required it can always be made up by addition or subtraction. Thus, 10, 5, 4, 1, make 20, as well as the division containing the 20 ohms.

250. There are other forms of resistance coils. But when very high-resistances are to be measured the multiplication of such sets would be cumbrous and costly. A device is therefore employed called a *shunt*, so-called because it *shunts* off a portion of the current and makes it branch. The whole of the current, therefore, does not go through the galvanometer, and the whole of the resistance to be measured is found by knowing the proportion in which the *shunt* relieved the galvanometer of the total resistance, and a little calculation gives the amount. A *shunt*, then, is a resistance coil of small resistance, and is constructed in close relation to the galvanometer which it is used with. Thus a galvanometer is made with a coil of a certain known resistance.

A shunt is made with a coil which is of such resistance that it will relieve the galvanometer of a certain fraction of the whole current. For example, it may be made to *shunt* off 4-5ths of the current. Hence it is known that only 1-5th will go through the galvanometer when the shunt is used with it. Whatever result is got by the trial must be multiplied by 5 to find the *actual* strength of current of the circuit under trial. Suppose a shunt and galvanometer of equal resistance, then of course half of any current goes through each, and to find the true value the reading or result given by the latter must be doubled.

251. We give an example of the employment of resistance coils and of a shunt, but cannot go beyond a a mere attempt to deal with the subject of electrical *testing*, which is a science in itself.

We have a magnetic needle in the middle of two similar coils, in fact, a Differential Galvanometer. We may suppose the currents passing through it are not of equal strength; or we may suppose the currents to be exactly equal, but the circuits of different resistances; the effect in either case is the same. The current through one circuit will be the stronger of the two, and since it passes in an opposite direction in each, the needle will be deflected by the superior force of the former, say, to the right hand. It is required now to make both circuits equal. We must evidently increase the resistance in the former circuit; we then put a resistance box in circuit, and pulling out the first plug see if the needle goes back to 0, the point at which it must stand if the whole resistance in both circuits be the same. If we find the coil thus introduced is not sufficient, we continue trying others, until the needle stands at 0. If the circuit to be measured were a telegraph line we should have found its resistance in this operation, this being the amount of resistance introduced by the box.

If, however, after pulling out all the plugs, the needle is not brought back to 0, it is evident that we have not enough resistance in the box to measure the other circuit; it is necessary to use a *shunt*. We suppose this introduced in the circuit. A certain proportion of the current is now diverted from the galvanometer, and the resistance coils are tried till the needle stands at 0. Whatever amount of resistance is found unplugged when this occurs must be multiplied by a figure, which depends on the relation between the galvanometer and the shunt, as above explained.

Our limits prevent us continuing the subject of the *shunt*. It is a form of Divided Circuit, and space would be necessary for its full consideration. We are also obliged to omit the explanation of the most complete method of testing resistance, known as "Wheatstone's Bridge." It is found in works on telegraphy, and in Professor Jenkin's "Electricity and Magnetism."

252. The measurement of resistance is of great importance in telegraphy, as it regulates the choice of materials and enables the electrician to test their quality. It is also indispensable in the discovery of faults, and in finding their position.

253. A fault in telegraphy means an impediment to signalling. The three kinds of faults are—1, a defect producing bad insulation; 2, a defect in the continuity of the line, or excessive resistance; 3, contact between two separate lines. The ordinary tests on a line are for the resistance of the conductor and the goodness of insulation. Generally speaking, it is by comparing the resistance which is found in the case of a fault with what the resistance of the line is when good that faults are detected. For example, if the resistance in a land line were found to be very much less than usual, it would probably be caused by the wire being broken and making what is called *dead earth*, that is, leading to the ground at some place short of the end of the circuit. If this were so, the circuit being much shorter would present less resistance, and consequently a larger deflection would be shown on the galvanometer. In testing for resistance of the conductor the line must be put to

earth at the further end, but in testing for *insulation* the line is left free at that end, and the operation is really that of testing the resistance of the insulators.

254. The distance of a fault is often very difficult to find accurately, but the principle may be roughly illustrated thus: the ordinary resistance (so many ohms) of a whole circuit being known, the resistance per mile is found by dividing the whole resistance by the length in miles; for example, if the whole resistance of a circuit A B were 1,000 ohms and the line 20 miles long, the resistance per mile would be 50 ohms. So, if the broken line made *dead earth*, the distance of the fault would be obtained by dividing the *observed* resistance by the 50. Then if at the other end a corresponding result is obtained the conformation is perfect. If the resistance, testing from A, were 400 and from B 600, the fault would be at 8 miles from A and 12 from B. But faults generally present difficulties which complicate the matter, and the explanation of their treatment is beyond our limits.

255. Testing for the position of faults in submarine cables can generally be done more accurately than in land lines, and the conditions allow of the employment of a wider range of instruments; this department is one of the most advanced in telegraphic science.

We may just say that an indispensable instrument in Cable testing is Sir W. Thomson's Quadrant Electrometer. An electrometer is an advanced form of electroscope, and enables us not merely to detect an electric charge in any body, but to measure its amount. This instrument has four brass quadrants which, as insulated Conductors, are arranged in pairs to show by comparison with each other the difference of electric condition or potential.

Want of space prevents our giving more than the above skeleton outline of this branch of Telegraphy.

In the *Engineer* for Nov. 8, 1872, is a paper on Galvanometers which thoroughly explains the relation of Trigonometry to this instrument.

CHAPTER XV.

REASONS FOR USING LIGHTNING PROTECTORS—CAUSE OF LIGHTNING—"POINT" DISCHARGE OF ELECTRICITY—EXPLANATION OF THE LIGHTNING CONDUCTOR—METHOD EMPLOYED IN FRENCH TELEGRAPH OFFICES.

256. Atmospheric electricity not being under human control, as frictional or chemical electricity is, it becomes sometimes very troublesome, and even dangerous, in its effects on telegraphic circuits. Special arrangements to prevent it from doing damage must be made in setting up all lines, whether "land" or "submarine." Telegraph cables especially should have lightning "protectors" at each end, and particularly in tropical climates. In spite of all precautions, accidents do happen; the results are demagnetising and cross-magnetising needles and other forms of magnet, fusing the coils of relays or Morse instruments, and giving unpleasant and, as already remarked, dangerous shocks to operators.

257. We must say a very few words as to the cause of the mischief. Electricity when produced, or its natural equilibrium disturbed, is ever seeking to recombine, and this fact, coupled with the laws which govern its action is the primary source of the effects which are found to follow. In certain states of the atmosphere the balance of electricity among the clouds, or between them and the earth, becomes disturbed. A cloud charged with one kind of electricity acts *inductively* on another cloud, or on the ground, and charges it with contrary electricity; and when the tendency to recombination exceeds the resistance of the air which separates them, the lightning spark passes from the one charged body to the other.

According to the laws of electrical action, the best conducting objects should receive the electrical *discharge* most readily, and, in fact, trees, lofty buildings, metals, and so forth, are generally struck by it. It is dangerous to stand under trees in a thunder-storm, especially if in the midst of a large common. It is said that oak and elm trees are particularly dangerous, but pine trees less so, as less *conductive*.

258. Electricity is said to concentrate itself on points, and, in fact, the distribution of electricity over bodies which have points is such that the *density*, or *quantity*, on a *given surface* becomes very great there, and the electricity will pass off in the shape of a spark or "brush." Anything tending to produce a great *electric density* at any part of the surface of a charged conductor tends to produce the spark. Thus by approaching a finger to a charged conductor, the *density* is increased by *induction* opposite the finger, and may be increased sufficiently to produce the spark. Points are also spoken of as collecting electricity from any electrified body held in the neighbourhood; their action is as follows:—If attached to an insulated conductor and held near an electrified body, A, they become charged by induction with the opposite kind of electricity. This flies off in sparks or by a silent discharge, and leaves the insulated conductor charged with the same electricity as that of A.* This property of points explains the action of lightning conductors. Lightning is an enormous electric spark passing between two clouds, or from a cloud to the earth. In the latter case the electrified cloud is attracted towards any prominence or good conductor, which becomes electrified by induction, and the spark passes under the conditions stated above. If the electrified prominent spot on the earth be armed with a point connected by good conductors to the earth, the electricity will pass off from the point into the air, and the prominent spot cannot be electrified highly by *induction*. Electricity is thus prevented from accumulating on the surface of the earth, and is harmlessly discharged by the pointed lightning-rod. Sometimes, however, the

* Professor Jenkin on Electricity.

charge is so abundant that the discharge by the point is not complete, and the lightning from the cloud strikes. It is then discharged into the earth by the conducting rod. Conveyed in this way by a good conductor, electricity leaves no trace of its passage; but a spark driven through a bad conductor tears it to pieces.

259. With regard to our particular subject, it will not be surprising that the long and widely-extended telegraph wires have been found to form a comparatively extensive range of conductors open to the influence of atmospheric electricity.* A number of inventions have been proposed to obviate or overcome the accidents that are always probable. They all depend on one general principle, and whether a whole building is to be protected or a single coil in a small telegraph office, the same conditions are imperative.

260. We proceed to describe the methods used in French offices, which are very good examples of the means for protecting instruments, &c., from lightning. These are of two different kinds. The first consists of protectors with points; the second of reel or bobbin protectors without points. In both is illustrated the great principle which caused us to liken a current of electricity to a lazy man. It always chooses the easiest path to travel on. These two kinds of protector may be used together or not; but the second is, in fact, a supplementary assistant to the other. The first kind serves to direct the electricity into the earth and insure its discharge; the second protects the instruments from the excess of fluid which might exist in spite of the protection given by the points.

261. In the first kind of protector there are two supports of brass or copper, which bear a number of points facing each other. They are separately insulated, and communication is made with the line at the top of

* We find that less importance is attached to this matter in England than on the Continent. In the tropics there is much danger of atmospheric disturbance.

one support, with the instrument at the foot of the same, and with the earth at the foot of the other. If electricity comes in by the line from the proper battery at the other station it will pass without diversion to the instrument; but if atmospheric electricity of too high a potential comes in by the line, the points collect it and pass it off to the earth at the place indicated. If it be in excess so as to endanger the instruments in spite of the point discharge, the other kind of protector can be employed.

262. This bobbin protector consists of a reel or rod divided into partitions alternately of brass and ivory. The first, third, and last are of brass, and the second and fourth of ivory. Thus the two portions at the top and bottom are separated from the central division by insulating plates. Communication is effected between the top and the bottom by a coil of fine silk-covered wire, to which the line is joined at the top and the instrument at the foot. At the central partition an earth wire is connected to the middle of the bobbin, but the silk covering insulates the wire coil from it.

An ordinary signalling current coming by the line passes from the top to the bottom through the coil, and there is no change in the arrangement. But if atmospheric electricity comes in, it will *fuse* the wire and escape to earth at the middle portion. To be effective the arrangement must satisfy the two following conditions: 1. Perfect communication between the first and fifth portion; 2. Perfect insulation between these and the central one.

THE END.

INDEX.

London: Printed by Jas. Truscott & Son, Suffolk Lane, City.